). UMTA-MA-06-0025-79-4,II

ENGINEERING TESTS AT DEPARTMENT OF TRANSPORTATION TRANSPORTATION TEST CENTER FINAL TEST REPORT
Volume II - Performance and Power Consumption Tests

Prepared by

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Surface Transportation Systems
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JUNE 1979

FINAL REPORT

DOCUMENT IS AVAILABLE TO THE PUBLIC THROUGH THE NATIONAL TECHNICAL INFORMATION SERVICE, SPRINGFIELD, VIRGINIA 22161

Transportation
Systems Center

Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
URBAN MASS TRANSPORTATION ADMINISTRATION
Office of Technology Development and Deployment
Office of Rail and Construction Technology
Washington, D.C. 20590

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Technical Report Documentation Page

1. Report No. UMTA-MA-06-0025-79-4, II	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle SLRV Engineering Tests at Department of Transportation Transportation Test Center Volume II--Performance and Power Consumption Tests		5. Report Date February 1979 6. Performing Organization Code 8-2700
7. Author(s)		8. Performing Organization Report No. DOT-TSC-UMTA-79-27,II
9. Performing Organization Name and Address The Boeing Vertol Company* Surface Transportation Systems Branch P.O. Box 16858 Philadelphia PA 19142		10. Work Unit No. (TRAIS) UM904/R9731 11. Contract or Grant No. DOT-TSC-1062
12. Sponsoring Agency Name and Address Department of Transportation Urban Mass Transportation Administration Office of Technology Development and Deployment, Office of Rail and Construction Technology, Washington DC 20590		13. Type of Report and Period Covered Final Report Jan - June 1976 14. Sponsoring Agency Code UTD-30

15. Supplementary Notes

*Under contract to: U.S. Department of Transportation
Research and Special Programs Administration
Transportation Systems Center
Kendall Square, Cambridge MA 02142

16. Abstract

In May 1973, Boeing Vertol Company was awarded a contract to build Light Rail Vehicles to a specification sponsored by Department of Transportation's Urban Mass Transportation Administration, and identified a Standard Light Rail Vehicle (SLRV).

Engineering testing on the SLRV was conducted by Boeing Vertol Company in accordance with the General Vehicle Test Plan GSP-064 at the Transportation Test Center, Pueblo, Colorado. The tests were conducted in conjunction with the Qualification Testing of three SLRV Production Pilot Cars (SF-0002, SF-0003, and MB-0002).

This report presents the results of the series of tests conducted in accordance with GSP-064. Volume I contains a description of the SLRV Test Program and the vehicle, and a summary of the test results; Volume II, Performance and Power Consumption Test Data; Volume III, Ride Quality, Noise, and Radio Frequency Interference Test Data; and Volume IV, a log of all tests collated by test objective and test vehicle.

17. Key Words General Vehicle Tests Light Rail Vehicle Transportation Test Center	18. Distribution Statement DOCUMENT IS AVAILABLE TO THE U.S. PUBLIC THROUGH THE NATIONAL TECHNICAL INFORMATION SERVICE, SPRINGFIELD, VIRGINIA 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	66	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

METRIC CONVERSION FACTORS

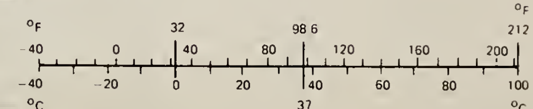
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 cm (exactly). For other exact conversions and more detailed tables, see NBS Misc. Pub. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit	°F



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1. INTRODUCTION

The United States Standard Light Rail Vehicle (SLRV) is currently in production at the Boeing Vertol Company for the Massachusetts Bay Transportation Authority and the San Francisco Municipal Railway. In order to develop a data base for quantitative comparison of the SLRV with other railcars and systems, testing was performed at the Rail Transit Test Track at Pueblo to the requirements of the TSC General Vehicle Test Plans (GSP-064).

1.1 SLRV ENGINEERING TEST PROGRAM

The general objective of the SLRV engineering test program was to:

> Establish a data baseline for the SLRV obtained in accordance with the General Vehicle Test Plans.
>
> Provide further experience in the use of the General Vehicle Test Plans in testing Urban Rail Vehicles.
>
> Conduct GSP-064 testing, when appropriate, in conjunction with ongoing qualification testing to minimize cost of data collection.

This report of the SLRV Engineering Tests is contained in four volumes.

Volume I	Introduction
Volume II	Performance and Power Consumption Tests
Volume III	Ride Quality, Noise and Radio Frequency Interference Tests
Volume IV	Data Logs

2. ACCELERATION TESTS

2.1 SUMMARY

Objective

The objective of the acceleration tests was to determine the SLRV acceleration characteristics, control response, line voltage, and load compensation effects throughout the operating range of the car.

Procedure

General Vehicle Test Plan P-2001-TT Baseline Test Procedure was integrated into the overall tests required for the qualification testing on three prototype SLRV vehicles.

Test Sequence

Data was recorded during acceleration testing in each of the test conditions listed in Table 2-1.

TABLE 2–1. ACCELERATION TEST DATA RECORDING

• AW0 Car Weight	SF0002 Test 37	Records 4-8	Single Car SF0002
	SF0002 Test 58	Records 1-4	2-Car Train MB0002/SF0002
	SF0002 Test 59	Records 1-4	
• AW2 Car Weight	SF0002 Test 23	Record 6-12	Single Car SF0002
	SF0002 Test 25	Records 1-10	Single Car
	SF0003 Test 30	Records 11-15	2-Car Train SF0003/MB0002
	SF0003 Test 31	Records 6-9	
• AW3 Car Weight	SF0002 Test 35	Records 2	Single Car
	SF0002 Test 74	Records 3, 4	
	SF0002 Test 68	Records 22, 23	2-Car Train SF0002/MB0002
	SF0003 Test 32	Records 1-4	2-Car Train SF0003/MB0002

Data was recorded at four controller inputs, three line voltages and three car weights. Data was also recorded for 2 car train units. All acceleration data has been recorded on magnetic tape. Single car data has been analyzed and is presented elsewhere in this section.

2.2 TEST DESCRIPTION

In general, acceleration testing consisted of accelerating the car to its maximum achievable speed on level tangent track at various combinations of master controller inputs, car weights, and track voltage. Runs were made in both directions over the same section of track. During

the acceleration, various car and traction system parameters were recorded to determine the characteristics of system operation.

2.3 TEST INSTRUMENTATION

The parameters listed in Tables 2-2 and 2-3 were recorded for all the acceleration testing. Two tapes were run in conjunction, cross referenced by the time signal, the event marker, the controller position signal and the longitudinal acceleration signals. The data recording equipment for the SLRV testing consisted of two tape decks, three oscillographs and separate signal conditioning for each type of test required. Descriptions of parameters, sensors, and calibrations are contained in Volume I of this report.

The quick look stripouts were used to validate instrument operation, define various time constants, define 'IHRIG' times for selection of data samples for analysis, and provide a check on calibration constants being utilized.

2.4 TEST PROCEDURES

The actual test procedures used during the SLRV testing were as defined by General Vehicle Test Plan for urban rail transit cars (UMTA-MA-06-0025-75-14) both for the preliminary pretest procedure and for the procedure at the test zone. For this series of tests it was not necessary to run any split tests — all accelerations were from zero to the desired maximum speed. Using the generalized acceleration procedures the following conditions were tested:

Controller Inputs — 25%, 50%, 75%, 100% Power

Track Voltages (Volts nominal) — 700, 575, 475

Car Weights (Pounds) — 69,130 (AW0) (+ crew), 82,500 (AW2), 100,945 (AW3)

The car was accelerated at the desired conditions with fixed input command.

2.5 TEST DATA

Data reduction was performed directly upon selected samples from oscillograph records and strip-outs from magnetic tape records of the test runs. Figure 2-1 presents typical data obtained from a maximum acceleration test of an 82,500-pound car.

Figure 2-2 presents a summary of SLRV acceleration data at four master controller inputs throughout the speed range of the car. A comparison of measured control linearity with design characteristics is contained in Figure 2-3. The resulting time-speed-distance characteristics for the four controller inputs are shown in Figure 2-4. The SLRV control system provides essentially proportional (i.e., proportional to 100-percent capability) acceleration control throughout the speed range.

From Figure 2-1, the acceleration jerk rate and control dead-time for a master controller input of 100 percent may be obtained. For 100-percent (full acceleration) input the total dead-time is 2.5 seconds and the jerk rate is 2.66 mph/sec^2.

The SLRV was tested at three car weights: AW0 – 69,130 pounds (empty car plus equipment plus crew), AW2 – 82,500 pounds (car plus 100 passengers), and AW3 – 100,945 pounds (car plus crush load). Figure 2-5 presents the acceleration data at three weights. As expected, the maximum acceleration decreases with increasing vehicle weight.

Time-speed-distance characteristics are shown in Figure 2-6.

The SLRV was designed for a normal operating track voltage of 575 volts. The propulsion system's sensitivity to off-design voltages (nominal 700 volts and 475 volts) was tested at AW2 (82,500-pound car weight) under full accelerating current demand. Figure 2-7 presents a summary of acceleration data at three voltage levels throughout the speed range of the car. The time-speed-distance characteristics associated with each voltage level are presented in Figure 2-8.

TABLE 2–2. PERFORMANCE TESTS: MAGNETIC TAPE RECORDS, TAPE A

Channel No.	Parameter	R Cal Volts	R Cal (Equiv Eng Units)	Quick-Look Use
1	Time (IHRIG)			X
2				
3	Axle Speed No. 1	10 V DC	49 mph	X
4	Axle Speed No. 2	10 V DC	49 mph	X
5	Control Setting	10 V DC	10 volts	X
6	Long. Accel	(0.342g)	7.5 mphps	X
7	Line Voltage	–10 V DC	2,000 volts	X
8	Brake Cylinder Press. No. 3	–	850.8 psi	X
9	Motor Field Current	–10 V DC	30 mps	X
10	Line Current No. 1	252 m V	1,000 amps	X
11	Event Marker		10 V = ON	X
12	Brake Cylinder Press. No. 1		838.5 psi	X
13	Motor Armature Current	–10 V DC	1,000 amps	X
14	Line Current No. 2	252 m V	750 amps	X

Record Mode FM; Tape Speed 7½ ips

TABLE 2–3. PERFORMANCE TESTS: MAGNETIC TAPE RECORDS, TAPE B

Channel No.	Parameter	R Cal Volts	R Cal (Equiv Eng Units)	Quick-Look Use
1	Time (IHRIG)	–	–	X
2				
3	Axle Speed No. 3	10 V DC	49 mph	X
4	Axle Speed No. 4	10 V DC	49 mph	X
5	Control Setting	10 V DC	10 volts	X
6	Long. Accel	(0.342g)	7.5 mphps	X
7	Slip/Slide Ident	10 V DC	10 V = Slip/Slide	X
8	Friction Brake Control A	10 V DC	10 V = No Brake	X
9	Slip/Slide Ident	10 V DC	10 V = Slip/Slide	X
10	Dynamic Brake Feedback	10 V DC	10 V = 100%	X
11	Slip/Slide Ident	10 V DC	10 V = Slip/Slide	X
12	Friction Brake Control B	10 V DC	10 V = No Brake	X
13	Event Marker	10 V DC	10 V = ON	X
14	Brake Cylinder Press No. 2	–	842.6 psi	

Record Mode FM; Tape Speed 7½ ips

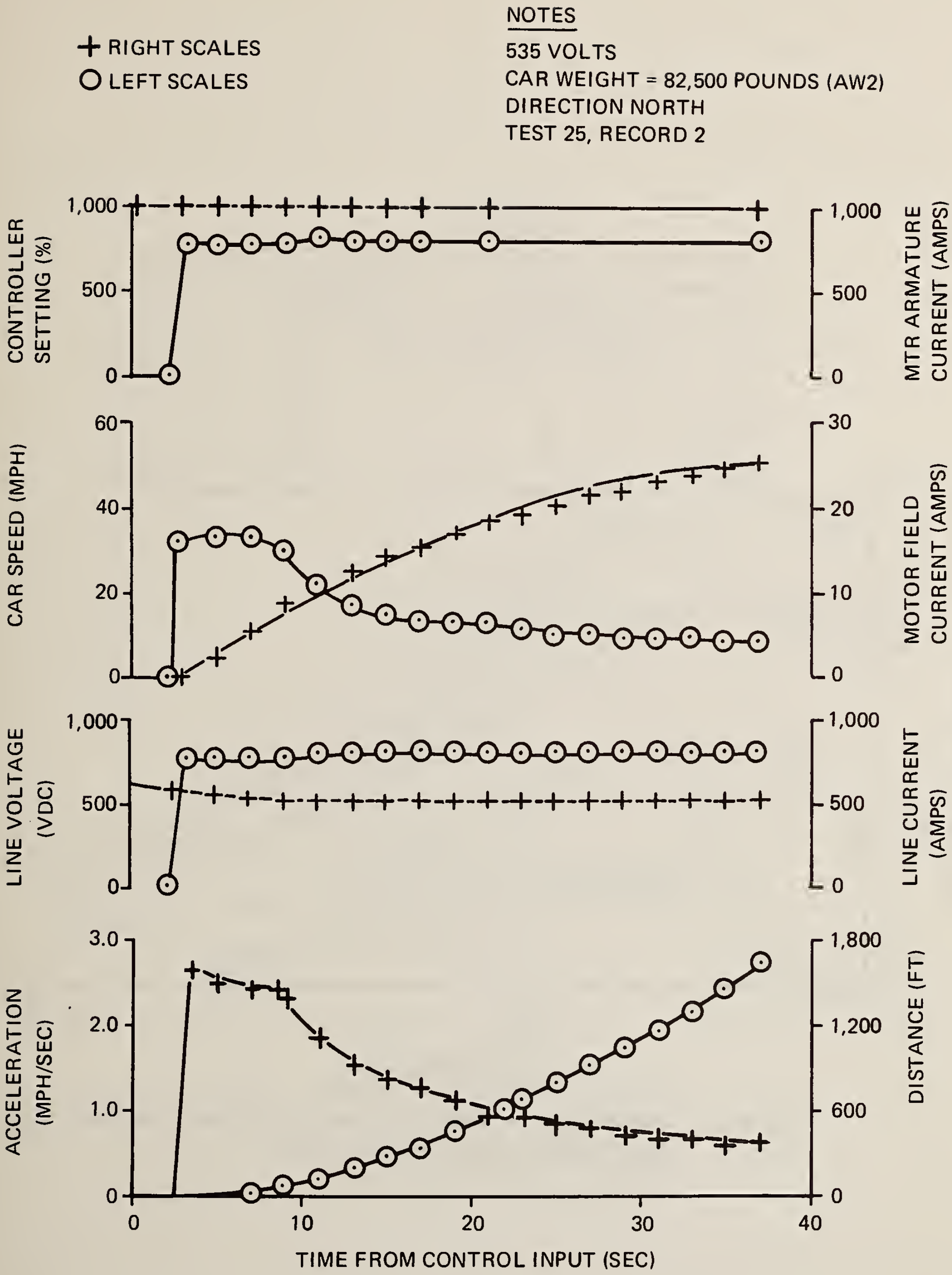


Figure 2—1. Typical Maximum Acceleration Data

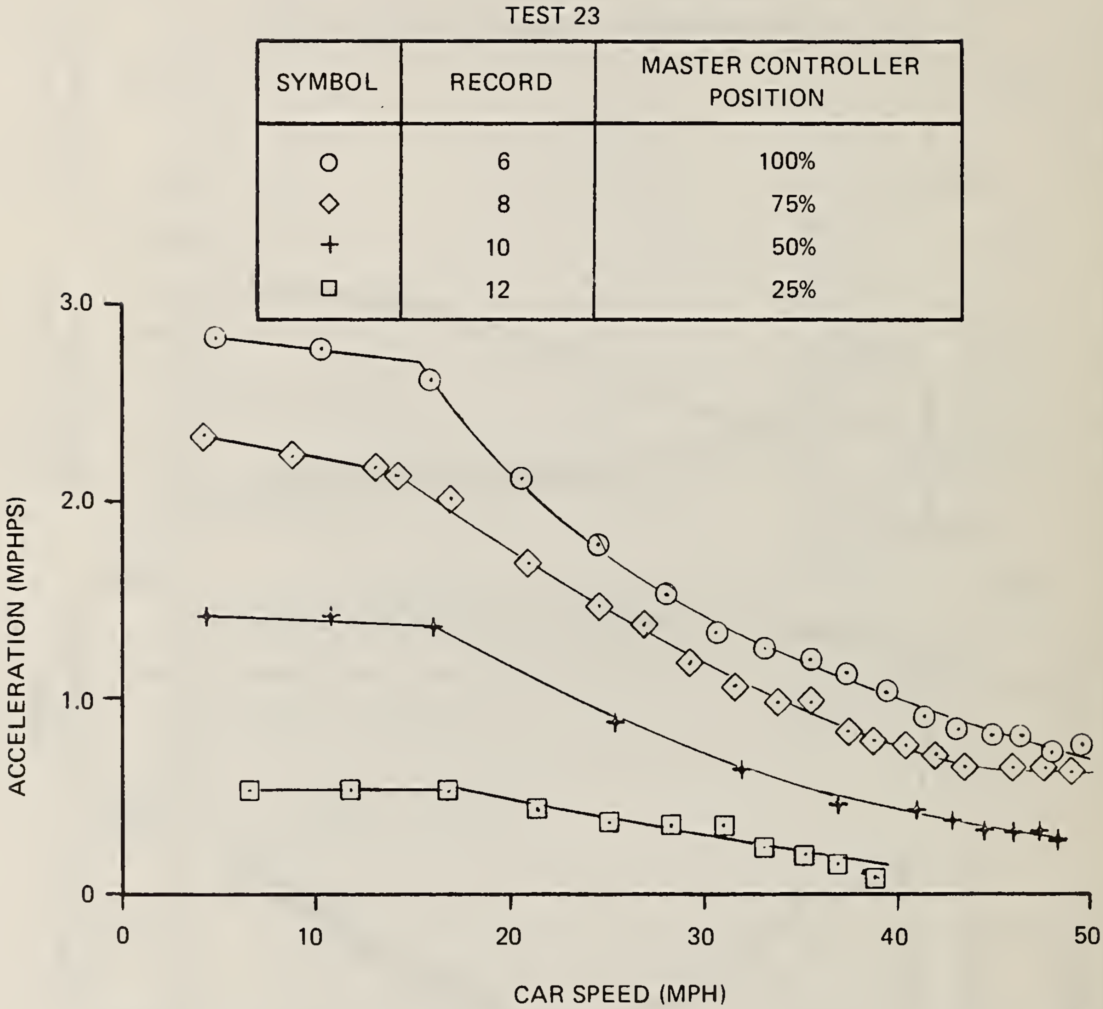


Figure 2–2. Acceleration vs Speed as a Function of Controller Position (82,500-Pound Car, Nominal Volts)

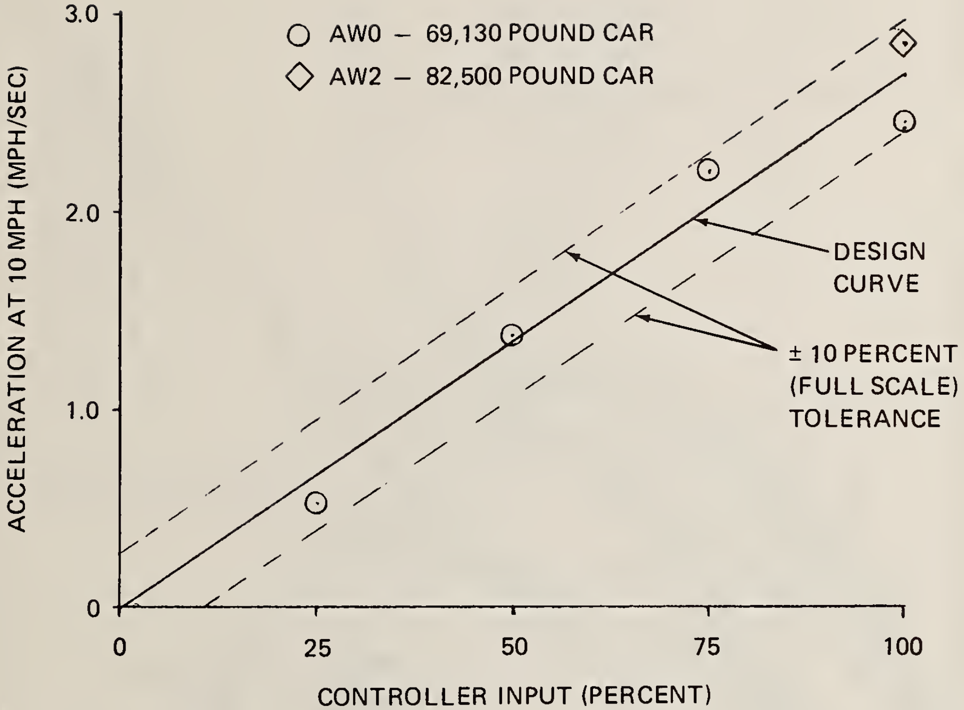


Figure 2–3. Control Linearity

TEST 23

SYMBOL	RECORD	MASTER CONTROLLER POSITION
○	6	100%
◇	8	75%
+	10	50%
□	12	25%

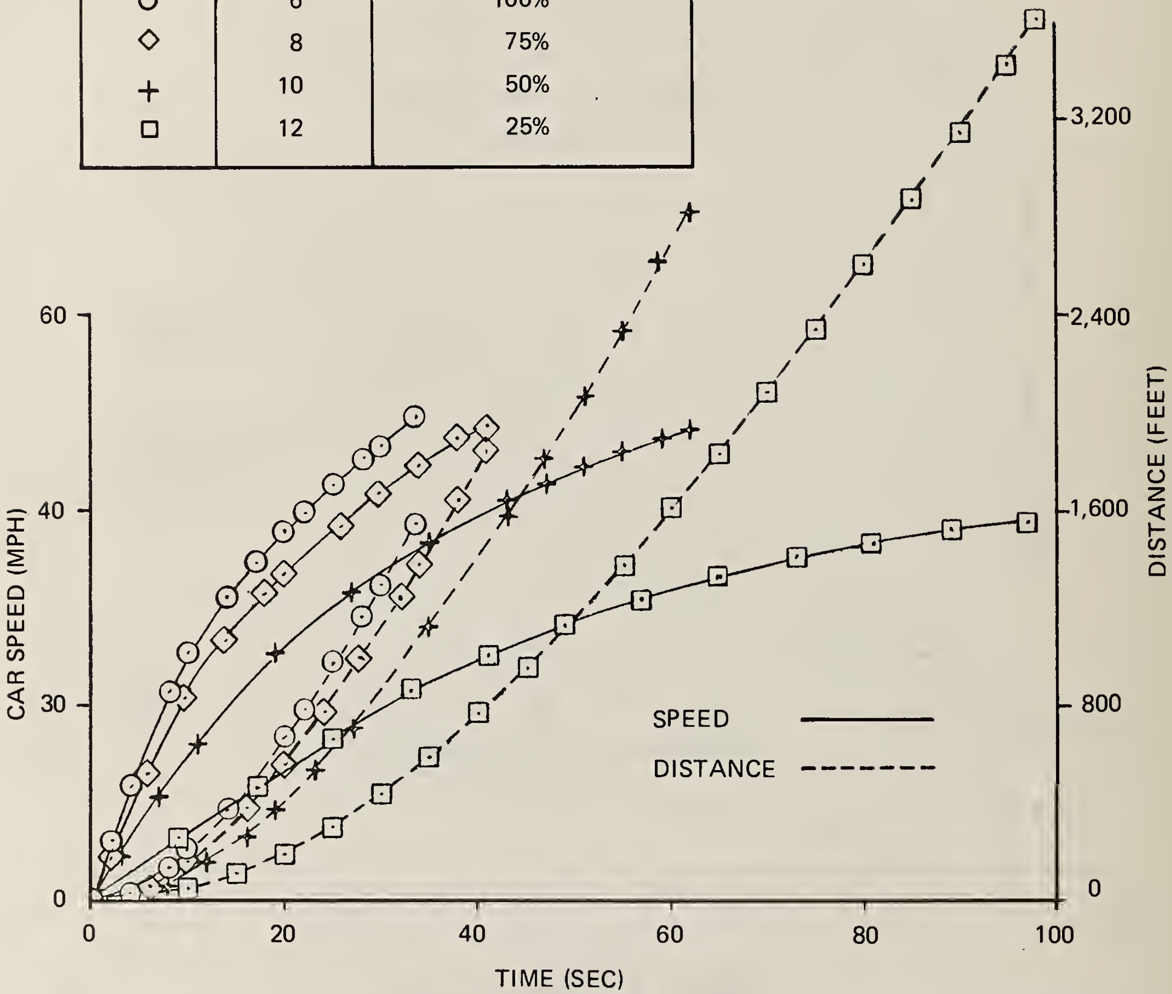


Figure 2–4. Effects of Control on Time, Distance, and Speed-to-Accelerate Characteristics (82,500-Pound Car, Nominal Volts)

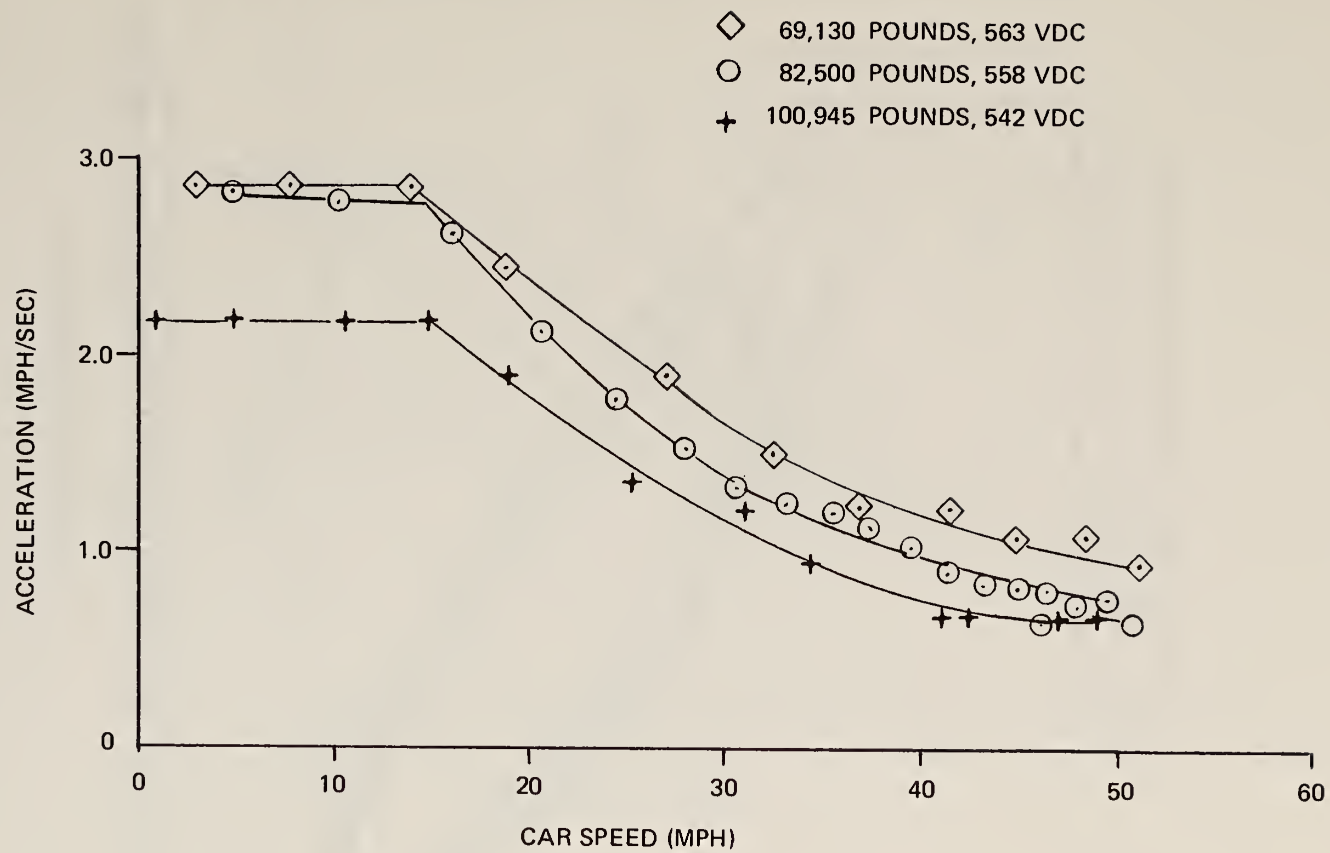


Figure 2–5. Acceleration Versus Car Speed as a Function of Car Weight

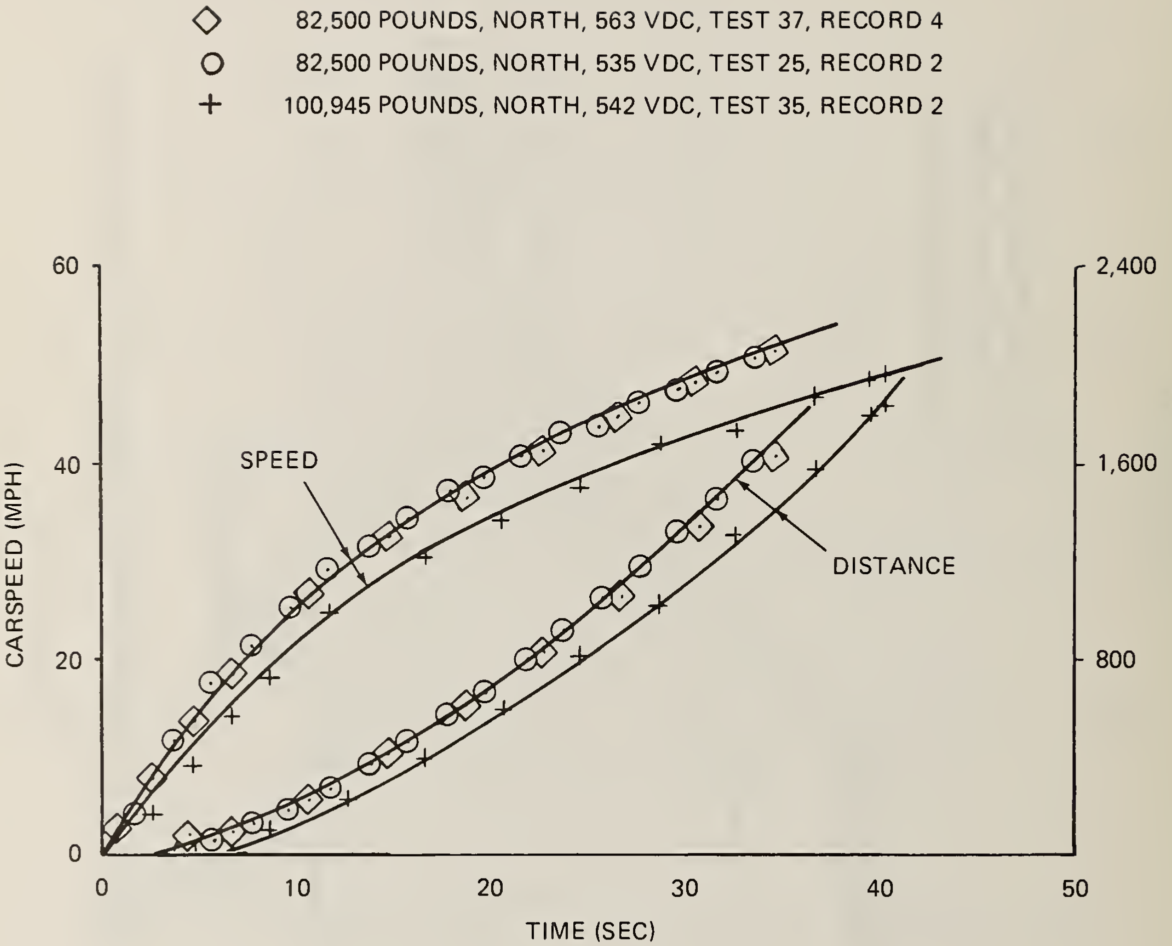


Figure 2–6. Car Weight Effects on Time, Distance, and Speed to Accelerate

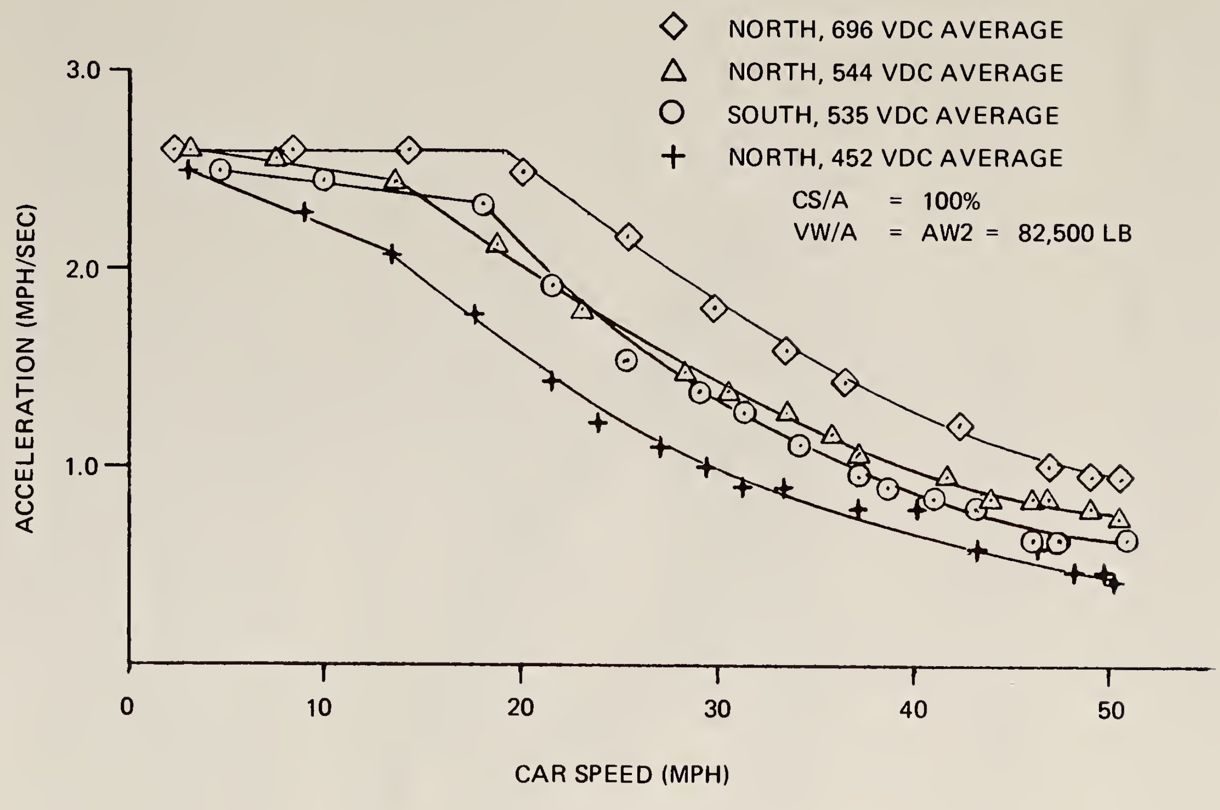


Figure 2–7. Acceleration Versus Speed as a Function of Line Voltage

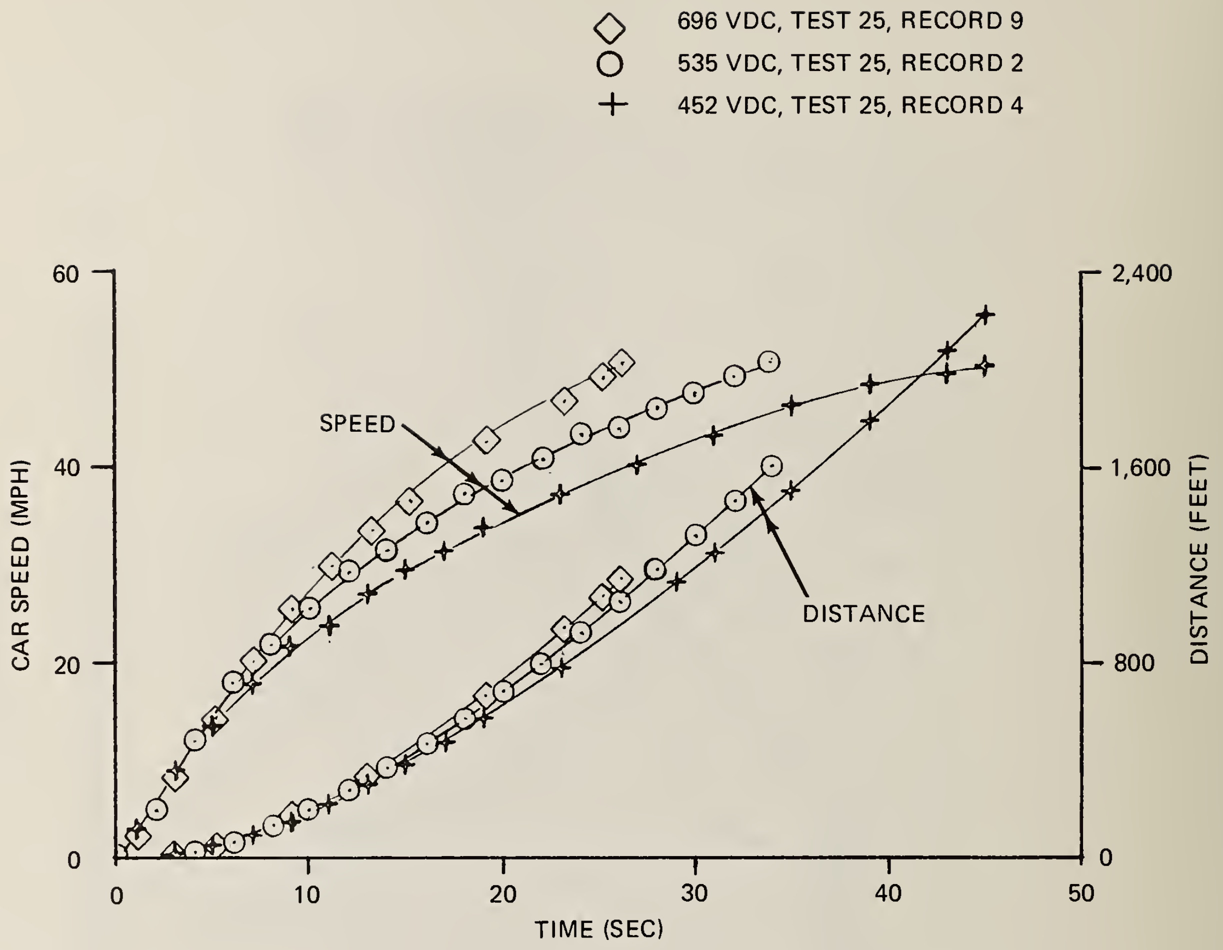


Figure 2–8. Voltage Effects on Time, Distance, and Speed to Accelerate (82,500-Pound Car)

3. DECELERATION TESTS

3.1 SUMMARY

Objective

The objective of the deceleration testing was to determine the overall characteristics and stopping distances associated with the four SLRV braking modes (blended, dynamic only, service friction only, emergency) throughout the operating range of the car.

Procedure

General Vehicle Test Plans P-3001-TT, P-3002-TT, P-3003-TT, and P-3004-TT baseline test procedures were integrated into the overall tests required for the qualification testing on three prototype SLRV vehicles.

Test Sequence

Data was recorded during acceleration testing in each of the test conditions listed in Table 3-1. Data was recorded at four controller input voltage levels and three car weights. Additionally, data for two car trains was also recorded. All deceleration data has been recorded on magnetic tape. Analyzed single car data is presented elsewhere in this section.

3.2 TEST DESCRIPTION

In general, deceleration testing consisted of bringing the car to rest from various initial speeds on level, tangent track at various combinations of master controller inputs, car weights, and braking modes. Runs were made in both directions over the same section of track. During the deceleration, various car and traction system parameters were recorded to determine the characteristics of system operation.

3.3 TEST INSTRUMENTATION

The parameters listed in Tables 2-2 and 2-3 were also recorded for all the deceleration testing. Two tapes were run simultaneously, cross-referenced by time signal, event marker, controller position signals, and deceleration signals. The data recording equipment for the SLRV testing consisted of two tape decks, three oscillographs, and separate signal conditioning for each type of test required. Descriptions of parameters, sensors and calibrations are contained in Volume I of this report. The quick look strip-outs were used to validate operation, to define various time constants, define IRIB times for selection of data samples for analysis, and to provide a check on calibration constants being employed.

3.4 TEST PROCEDURES

The actual test procedures used during the SLRV testing were as defined by "General Vehicle Test Plan (GVTP) for Urban Rail Transit Cars", (UMTA-MA-06-0025-75-14). Using the generalized braking procedures, the following conditions were tested:

TABLE 3–1. DECELERATION TESTS

TEST SET NO.	TEST NAME	WEIGHT	TEST NO.	RECORD NO.	TAPE NOS.	NOTES
P-3001	Deceleration Blended Brks	AW0	37	11–23	A 3, B 3	
		AW2	23	17–27	A-2, B 2	
			82	3–1B	A 9, B 9	2 Car
			86	4–7	A 11, B 11	2 Car
		AW3	69	1–18	A 6, B 6	
			74	1, 2	A 8, B 8	
			32 (SF3)	5–12	A 15, B 15	2 Car
			81	1–6	A 9, B-9	2 Car
			5	11–14, 16–20	A 1, B-1	
P-3002	Deceleration Friction Brks	AW0	37	24–29	A 3, B-3	
			3B	1–12	A 4, B-4	
			66	6–11	A 5, B-5	2 Car
			33 (SF3)	1–9	A 15, B 15	2 Car
		AW2	23	30–37	A 2, B 2	
			82	23–25	A 9, B 9	2 Car
			86	9–11	A 11, B 11	2 Car
		AW3	35	39–46	A 3, B 3	
			77	1–8	A 8, B B	2 Car
P-3003	Deceleration Dynamic Brks	AW0	6	9–17	A 1, B 1	
			38	19–26	A 4, B 4	
			39	1–8	A 4, 8 4	
			66	1–5	A 5, B 5	2 Car
		AW2	24	9–17	A 2, B 2	
			82	29–31	A 9, B 9	2 Car
		AW3	69	35–46	A-6, B 6	
			6	2–8		No mag tape
P-3004	Deceleration Emergency Brk	AW0	39	21–33	A 4, B 4	
			66	12–17	A 5, B 5	2 Car
		AW2	24	18–25	A-2, B-2	
			82	27, 28	A-9, B 9	2 Car
			34 (SF3)	11–20	A 15, B 15	
			31 (SF3)	1–5	A-15, B 15	2 Car
		AW3	35	5–24	A-3, B-3	
			77	2–7	A 8, B-8	2 Car
			81	7–15	A-9, B-9	2 Car (modified)

Controller Inputs – 25%, 50%, 75%, 100%

Car Weights (Pounds) – 69,130 (+ crew), 82,500, 100,945

The car was decelerated at the desired conditions with fixed input commands.

3.5 TEST DATA

Data reduction was performed directly upon selected samples from oscillograph records and strip-outs from magnetic tape records of the test runs. All records are available for reduction and analysis as deemed necessary.

Blended Braking

Figure 3-1 presents a summary of blended braking test data over the range of car speeds and controller inputs. The relatively flat curves indicate that satisfactory blending of the dynamic and service friction braking systems is obtained. As shown in Figure 3-2 the control linearity is within the 10 percent (full scale) tolerance band applied to the design characteristic.

Figure 3-3 presents the time and distance to stop from 50 mph for a range of controller positions.

The effect of car weight on deceleration rate at two control inputs is shown in Figure 3-4. As expected an increase in car weight results in a slight decrease in deceleration rate. The data for a car weight of AW2 was not included, due to the relative closeness of the AW0 and AW3 data. The time and distance to stop from various initial speeds for two car weights are presented in Figure 3-5. The effect of the car weight is quite slight.

Dynamic Braking

The service friction brakes were disabled for these tests. Figure 3-6 presents the deceleration rate and control linearity of the dynamic brakes. Time, distance and speed to decelerate are shown in Figure 3-7, while Figure 3-8 presents stopping distances from various initial speeds.

Emergency Braking

Figure 3-9 presents both the braking rates throughout the SLRV's speed range, and the total time to stop.

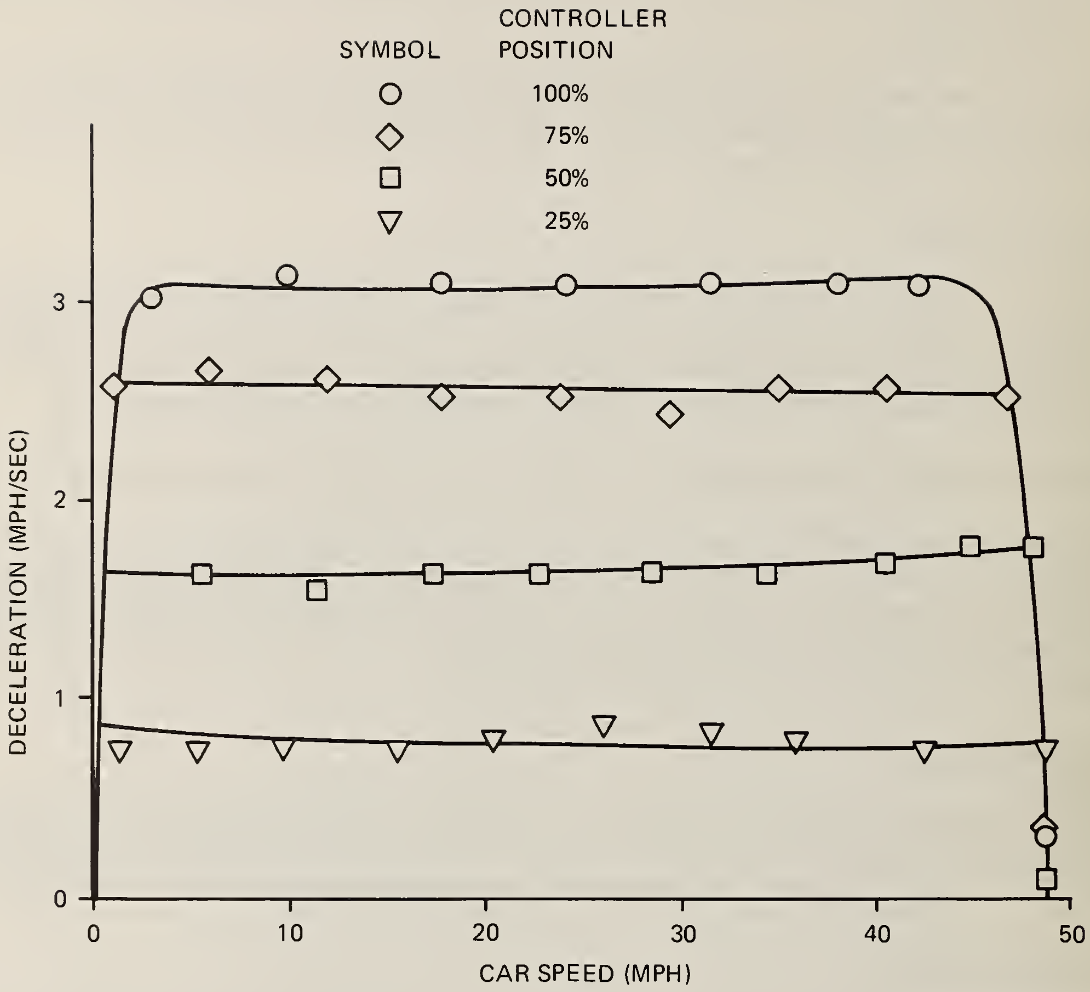


Figure 3—1. Effects of Controller Position on Blended Braking (100,945-Pound Car)

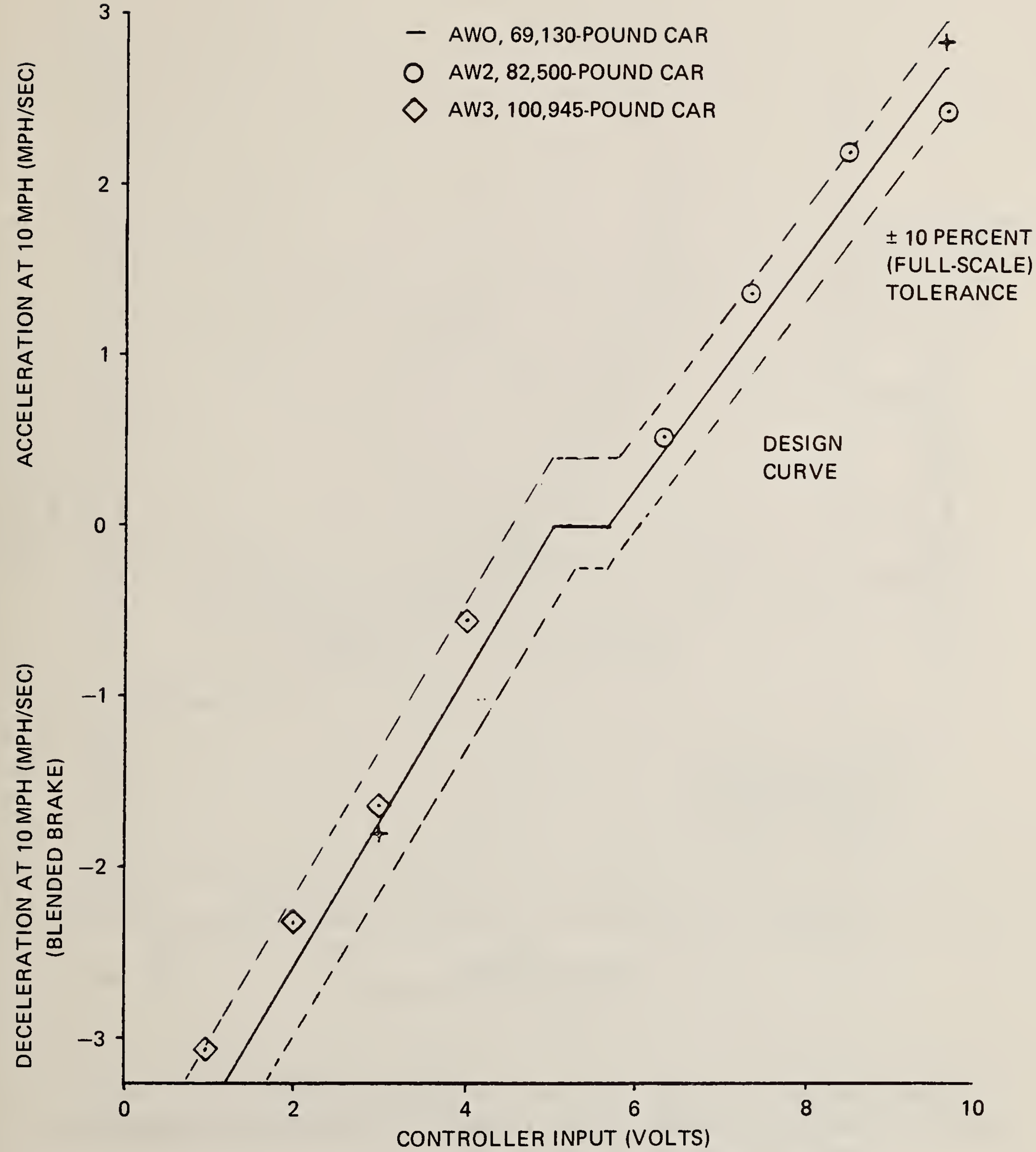


Figure 3–2. Control Linearity

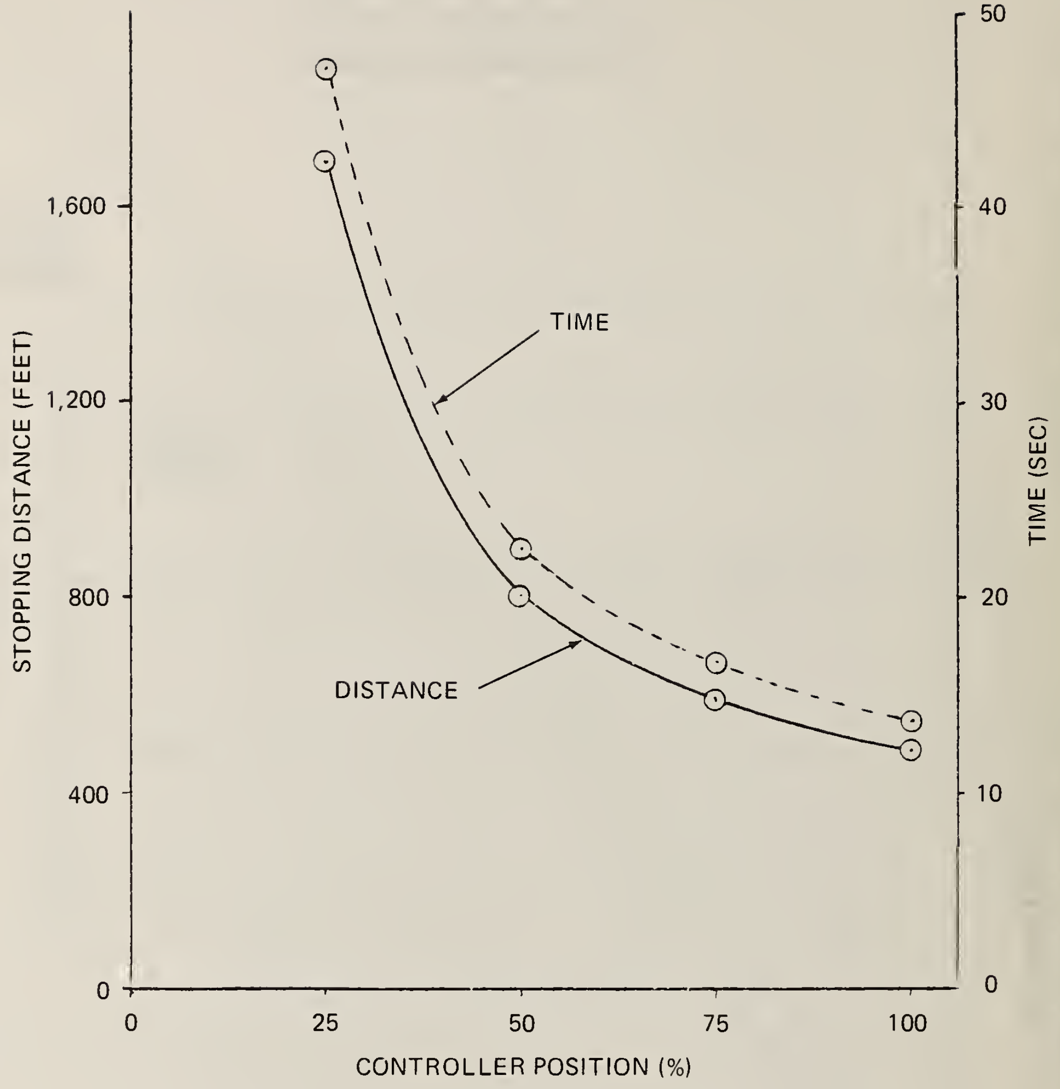


Figure 3–3. Effect of Controller Position on Blended Braking Stopping Distance from 50 mph, 100,945-Pound Car (AW3)

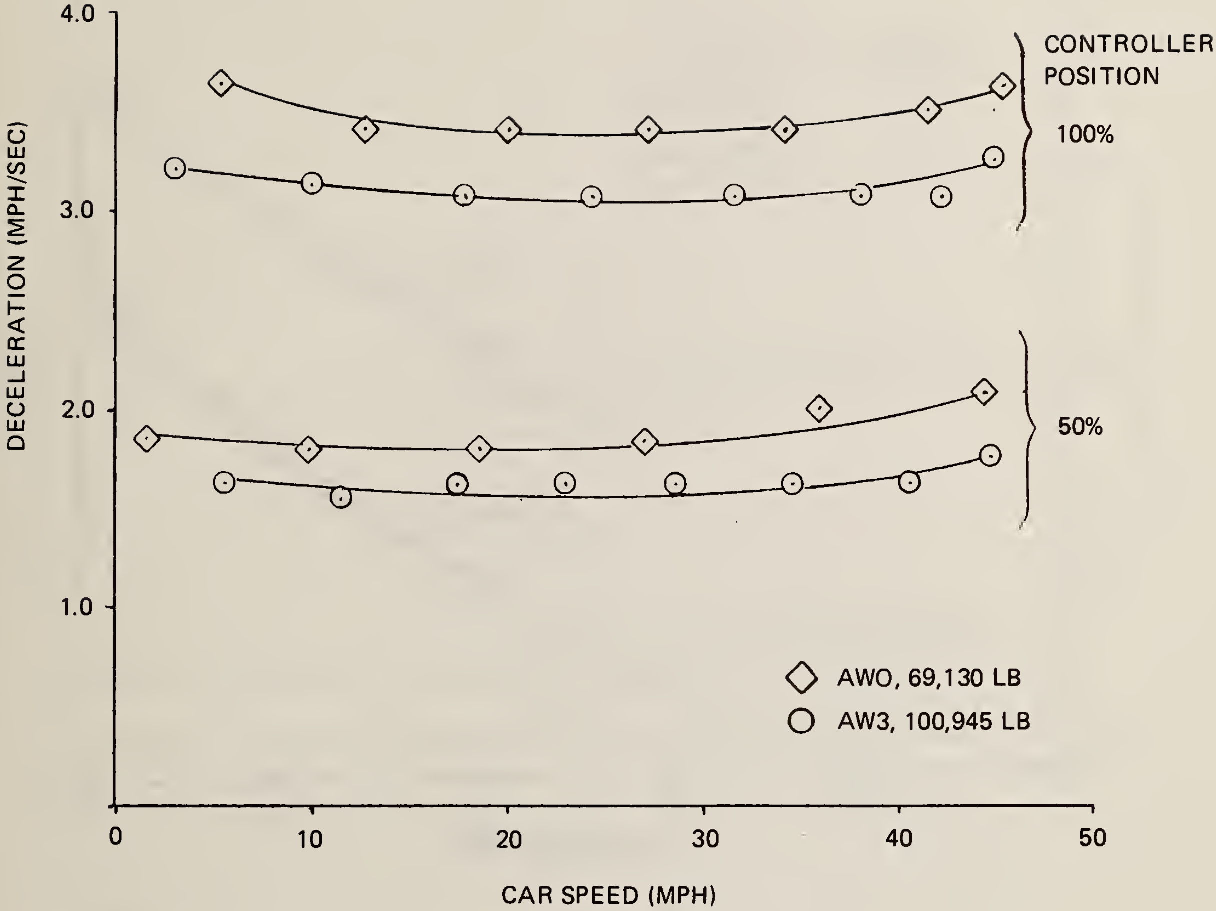


Figure 3–4. Effects of Car Weight and Controller Position on Blended Braking

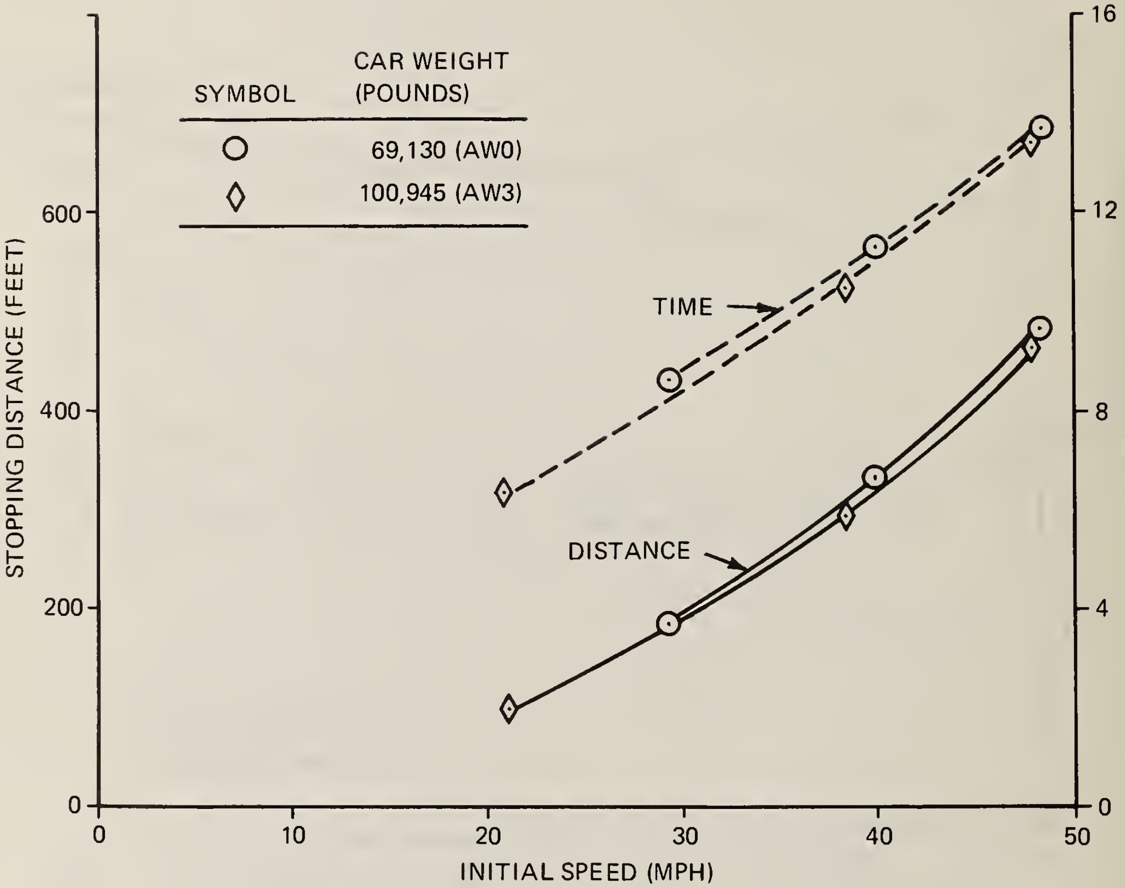


Figure 3–5. Effect of Car Weight on Blended Braking Stopping Distance

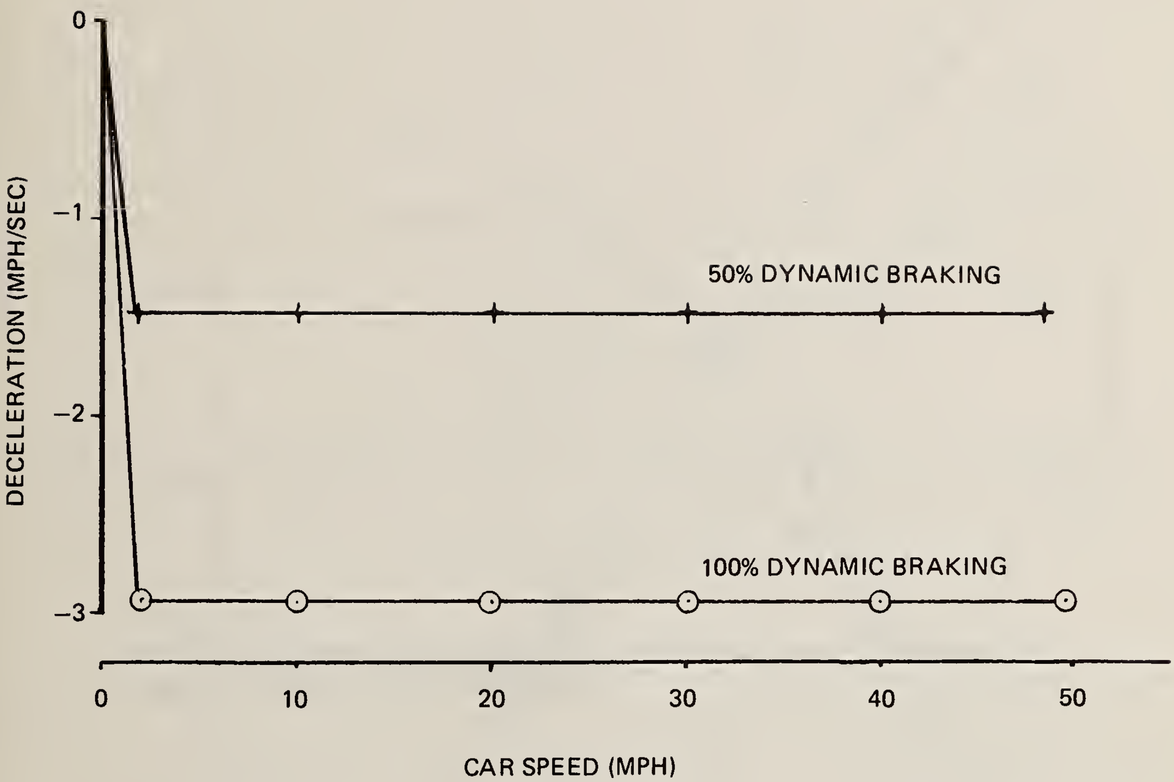


Figure 3–6. Deceleration of 69,130-Pound Car (AW0) in Dynamic Braking at Nominal Track Voltage

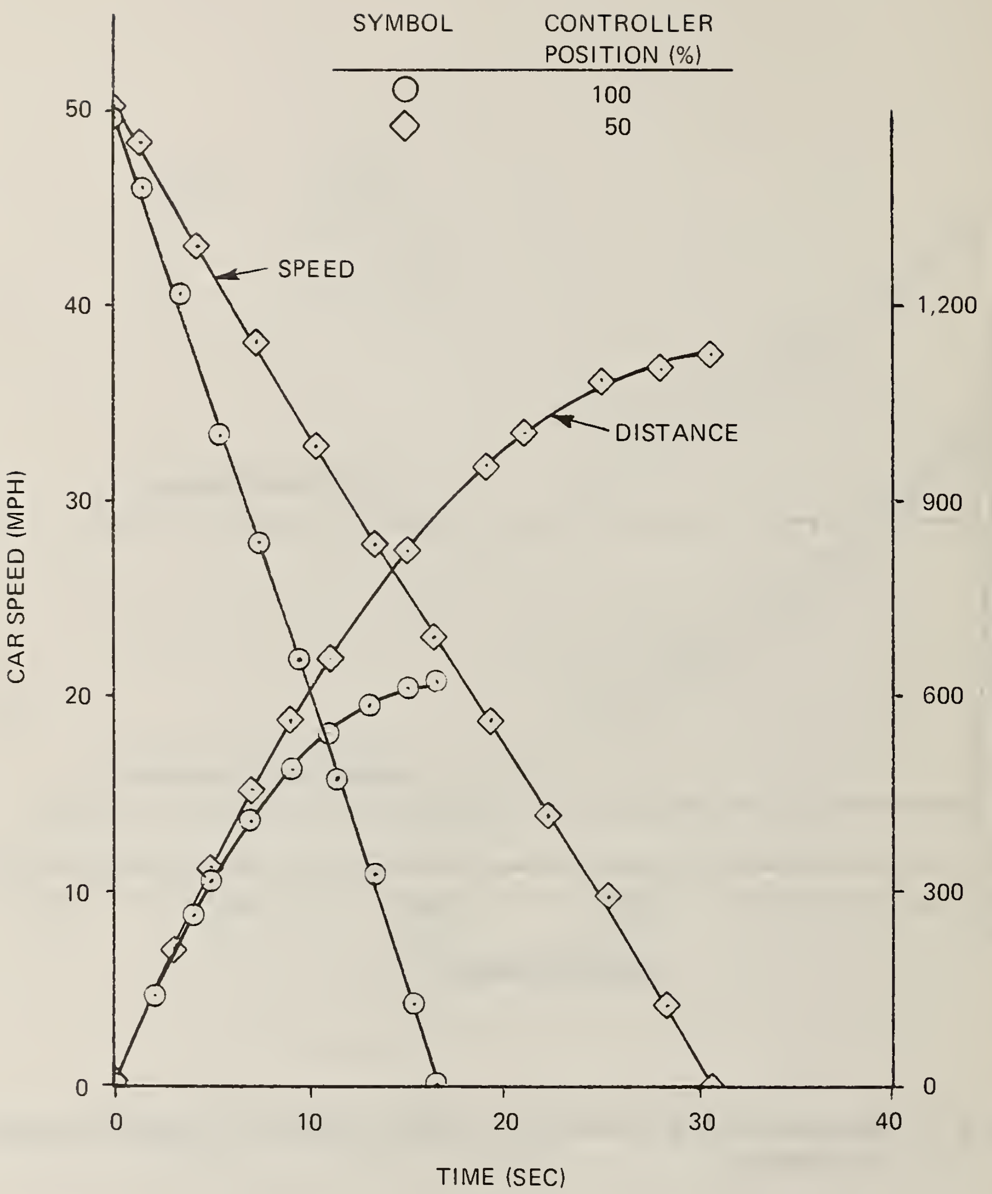


Figure 3–7. Dynamic Brake Control Characteristics Time, Distance, and Speed to Declerate (AWO, 69,130-Pound Car)

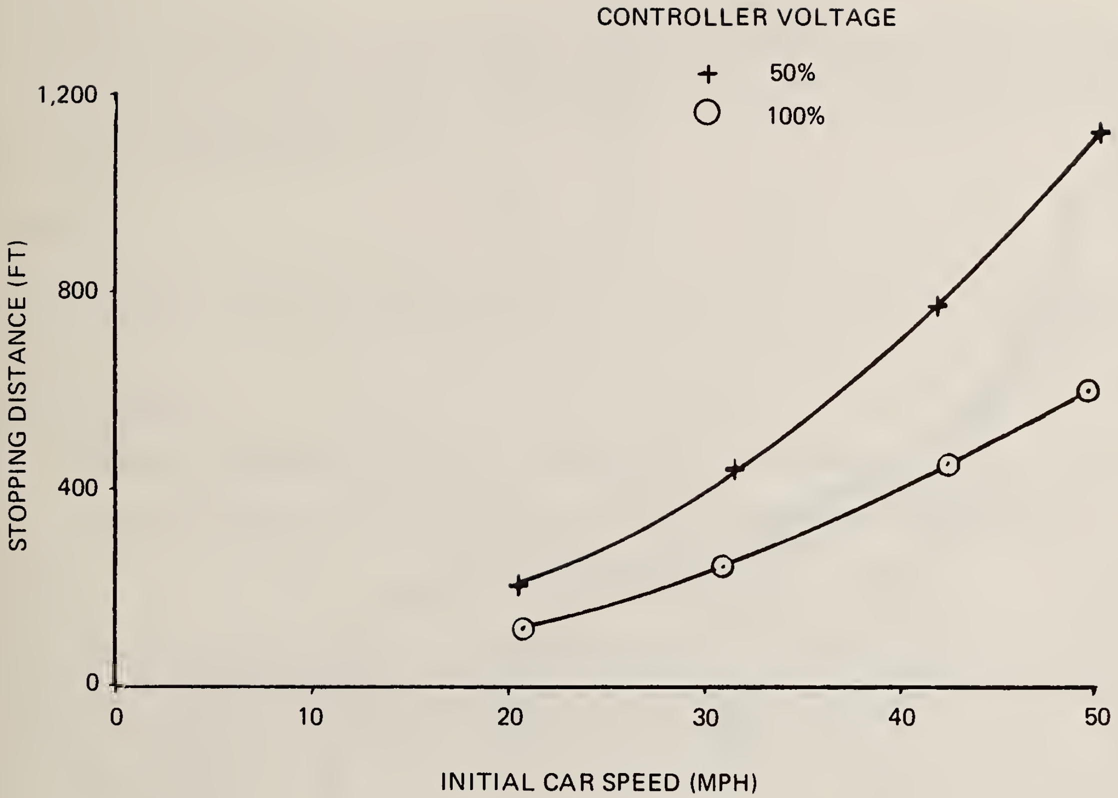


Figure 3–8. Dynamic Braking, Stopping Distances, Control Characteristics (AW0, 69,130-Pound Car)

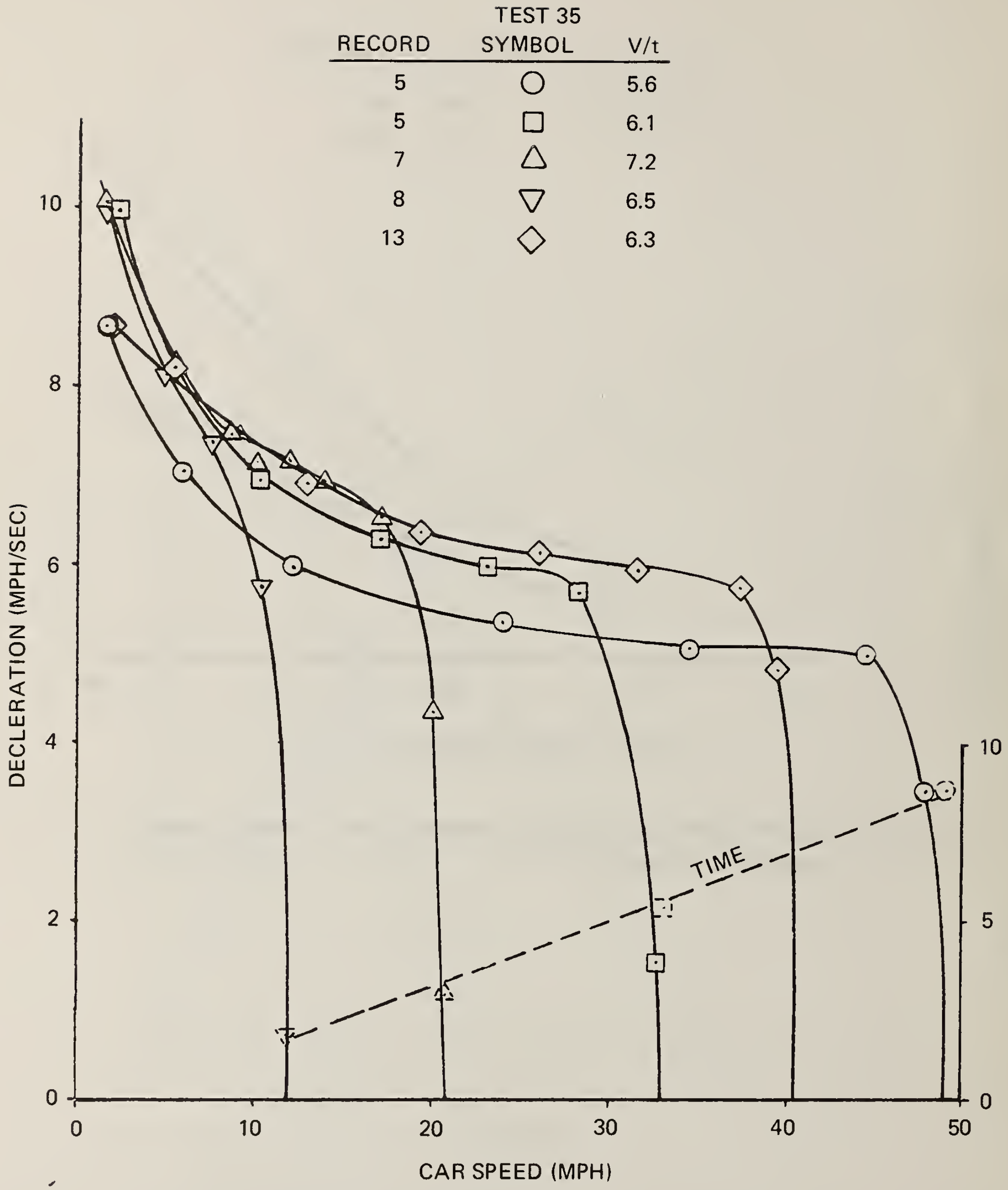


Figure 3—9. Emergency Braking Deceleration Profile (AW3, 100,945-Pound Car)

4. TRACTION RESISTANCE (DRIFT) TESTS

4.1 SUMMARY

Objective

The objective of the traction (train) resistance testing was to determine the traction resistance of the SLRV for use in the analysis of adhesion test data, to check the coefficients used to calculate the design performance of the vehicle and as a baseline for analysis of the vehicle tractive and braking effort values.

Procedure

General Vehicle Test Plan P-4001-TT Baseline Test Procedure was used for both single and two-car tests.

Test Sequence

Single Car – Test Run 25, Records 1 through 8 (Car SF-0003)

Two-Car Train – Test Run 30, Records 2 through 9 (Cars SF-0003, MB-0002)

Status

The drift tests were conducted on the 6th and 15th of June 1976 at the DOT TTC facility in Pueblo, Colorado. Tests were conducted utilizing a range of entry speeds from 50 mph to 5 mph on cars adjusted to the AW2 specified weight of 82,500 pounds.

4.2 TEST DESCRIPTION

The SLRV SF-0003 car was tested on the level tangent section of the test track, following the Drift Test Procedure, SLRV-P-4001-TT. Tests to determine the single car resistance were performed during Test 25, Records 1 through 8, on June 6, 1976, at the AW2 car weight. Two-car train drift tests were performed during Test 30, Records 2 through 9, on June 15, 1976.

4.3 TEST INSTRUMENTATION

The parameters instrumented and recorded during the drift tests were the same as those recorded during the other performance testing. Tables 2-2 and 2-3 present the listing of instrumented data channels and the various locations of the recorded data.

4.4 TEST PROCEDURES

The tests were performed at drift entry speeds of 50, 40, 30 and 5 mph (15 mph with two-car test). Each test was conducted from the north and south directions. The fairing through the test data is representative of the north and south direction since there was zero wind. The scatter of the test data is due to the sensitivity of the differential speed and differential time calculations performed to obtain the train resistance.

As specified in the GVTP, the train resistance is calculated at

$$TR = \frac{a}{21.95} [W + ew]$$

where W = The test vehicle weight in pounds
ew = The equivalent weight of rotating parts in pounds and
a = The measured deceleration rate in miles per hour per second
for the tested vehicle at AW2.

Then W = 82,500 pounds and
ew = 7,095 pounds.

The test fairing presented in Figure 4-1 was derived from the fairing presented in Figure 4-2 excluding the gearbox, motor brush, friction and windage losses. The calculations utilized the following information provided by Garrett AiResearch:

a. Watt losses for motor, friction and windage losses as a function of motor rpm, as shown in Figure 4-3.

b. Horsepower losses =

$$5.7 \times 10^{-4} N + 1.64 \times 10^{-5} (N)^2 + 1.39 \times 10^{-5} (N)^{0.85} T$$

where N = Axle rpm (from vehicle speed)
T = Axle torque (utilizing test train resistance)

The estimated train resistance is based on the Davis equation coefficients:

$$TR = 1.3W + 29n + .045WV + [\,(.0024) + (N\text{-}1)\,(.00034)\,]\,AV^2$$

where TR = train resistance in pounds
W = weight per train in tons
n = number of axles
V = train speed in mph
N = number of cars in train.
A = frontal area of lead car, 90 ft^2

4.5 TEST DATA

Reproductions of the acquired test data are shown in Figures 4-4 and 4-5 for single car drifting, and Figures 4-6 and 4-7 for drifting of a two-car train. The resolution of the results of these two test sets into train resistances are presented in Figures 4-3 and 4-8, respectively.

The train resistance derived from test data is approximately 85 pounds higher than the estimated values below base speed, providing a slightly higher rolling resistance. Above 20 mph the test fairing is in reasonable agreement with the estimated train resistance.

The test results indicate that the predictions made by Boeing Vertol for energy consumption on the actual N-line duty cycle were not influenced by use of the estimated train resistance (an input for energy consumption calculations) since there is no great difference between estimated and test data. The Δ train resistance of 85 pounds reduces the acceleration rate by 0.02 mphps or requires a 0.7-percent increase in tractive effort to maintain the 2.8 mphps acceleration rate of an AW2 car.

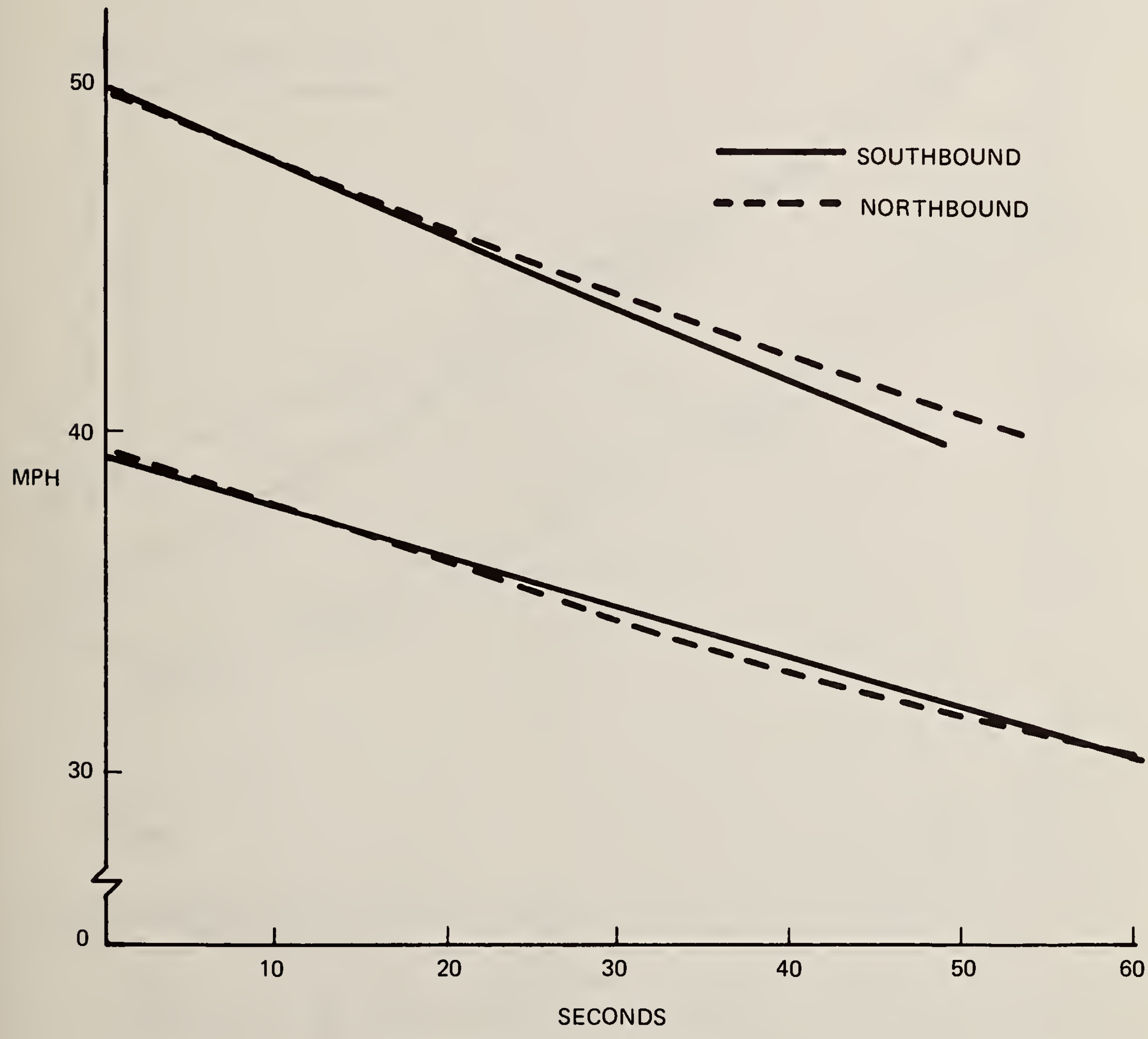


Figure 4–1. Drift Tests, Single Car (AW2) (Test 25 R.1-4)

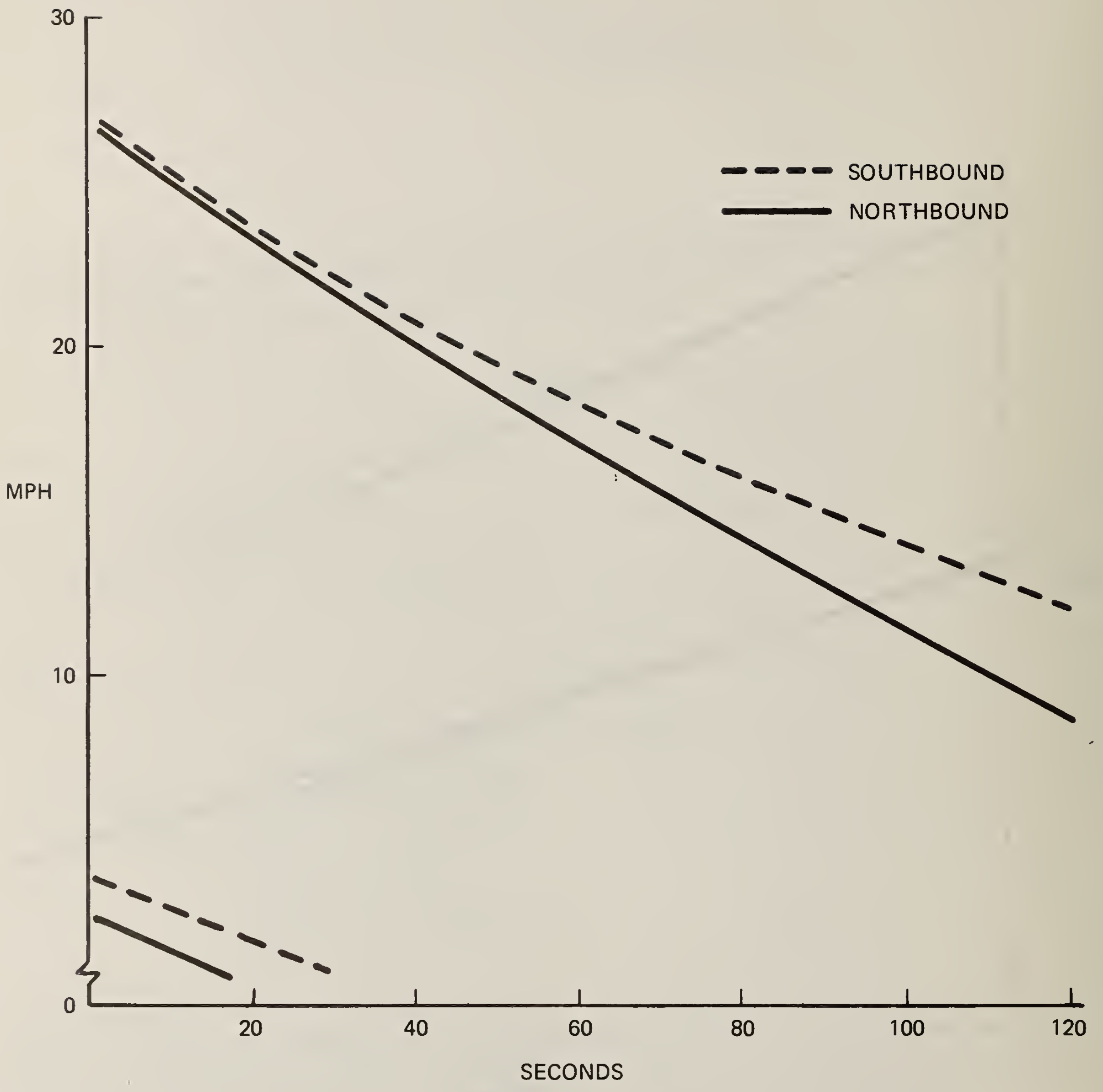


Figure 4–2. Drift Tests, Single Car (AW2) (Test 25 R. 5-8)

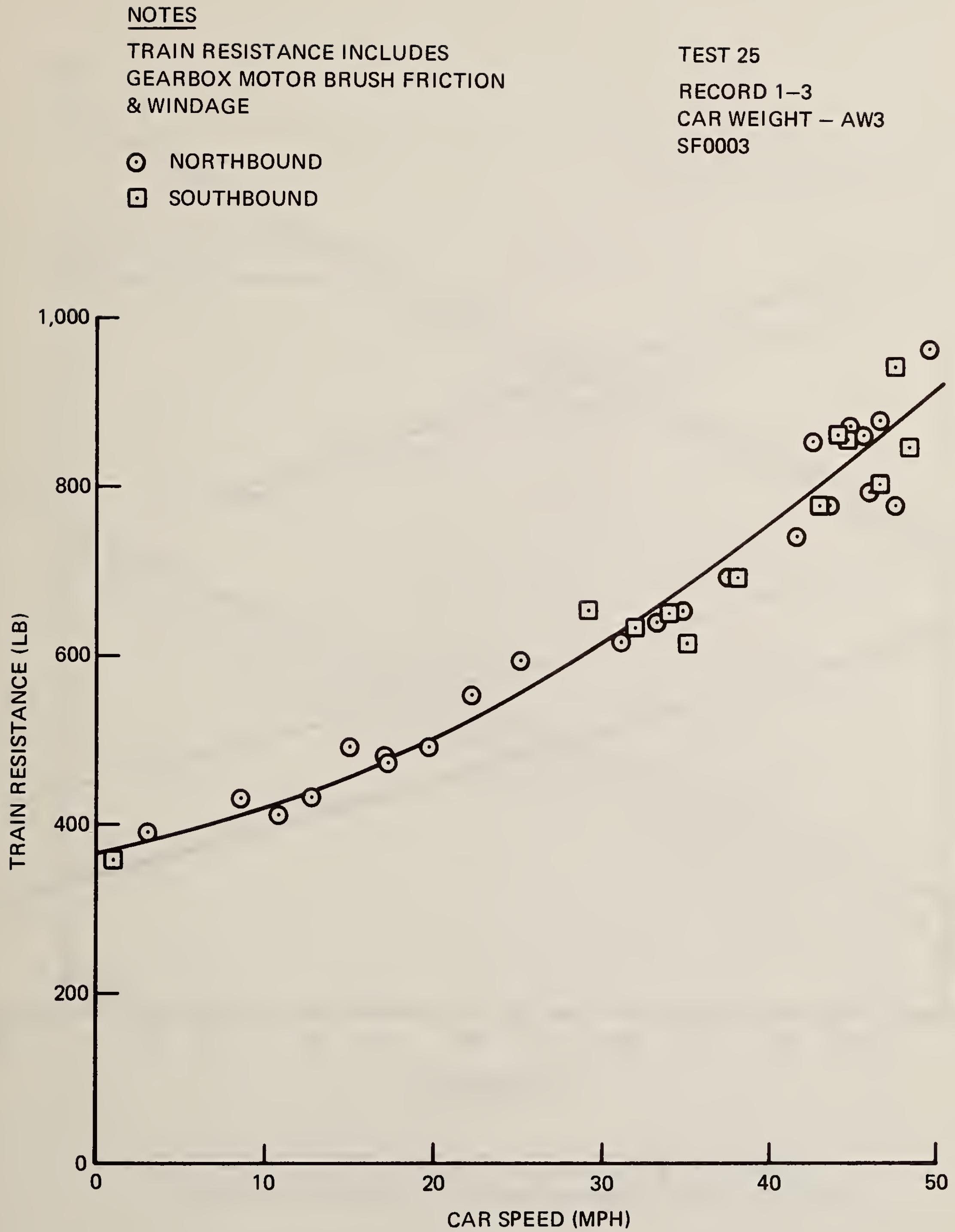


Figure 4–3. Drift Test, Single Car, Pueblo Test Center

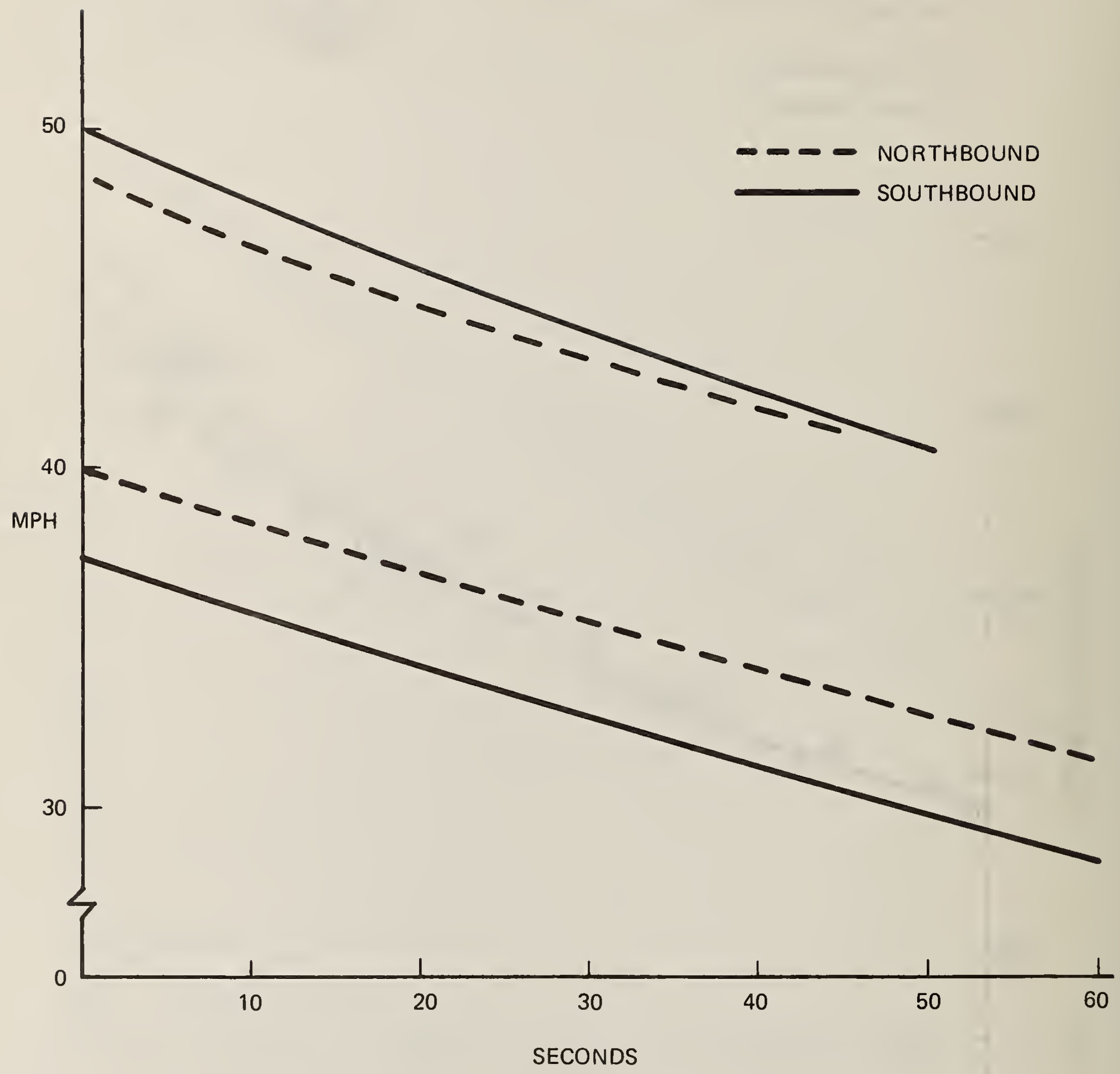


Figure 4–4. Drift Tests, Two-Car Train (AW2) (Test 30 R.2-5)

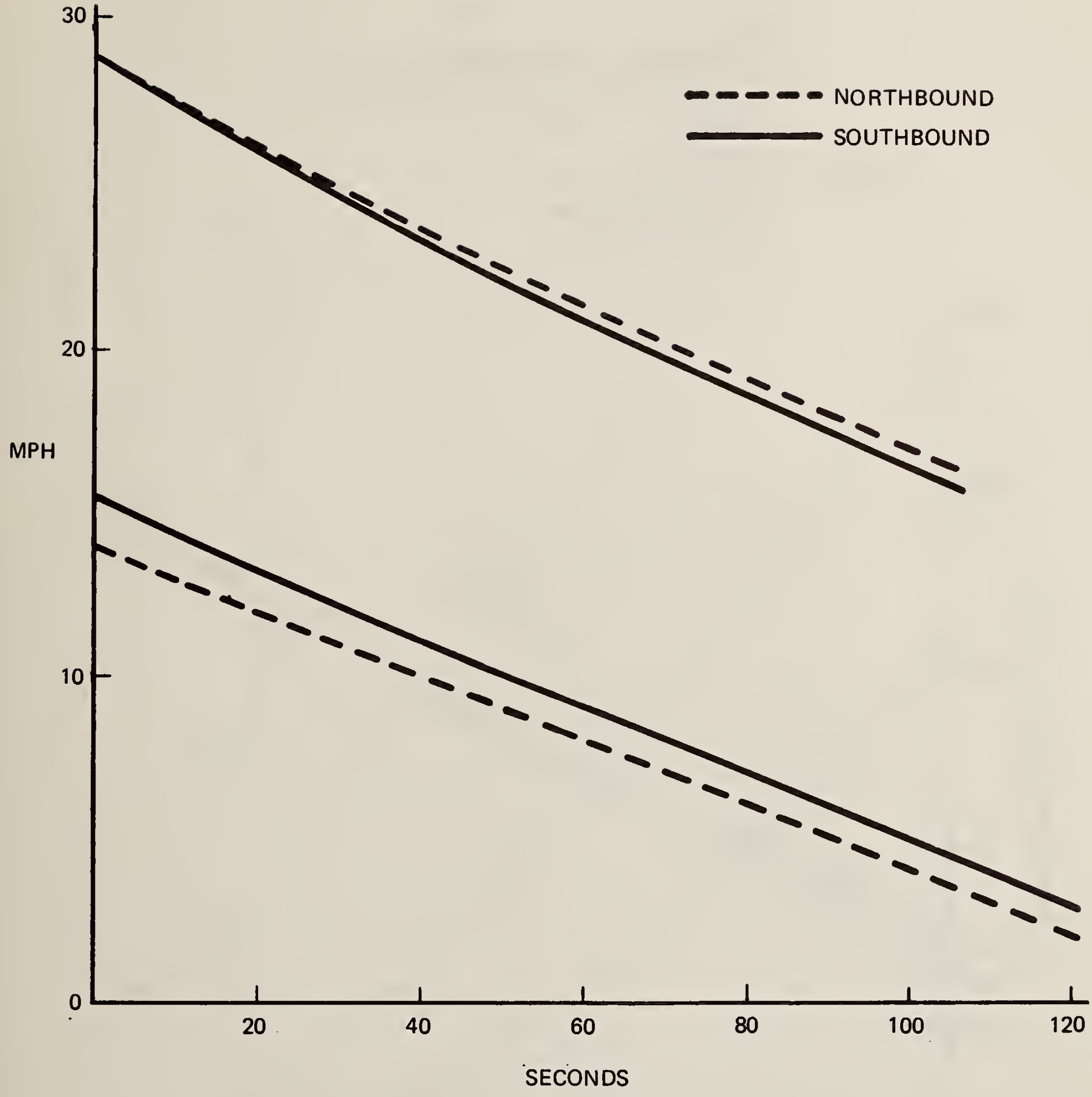


Figure 4—5. Drift Tests, Two-Car Train (AW2) (Test 30 R.6-9)

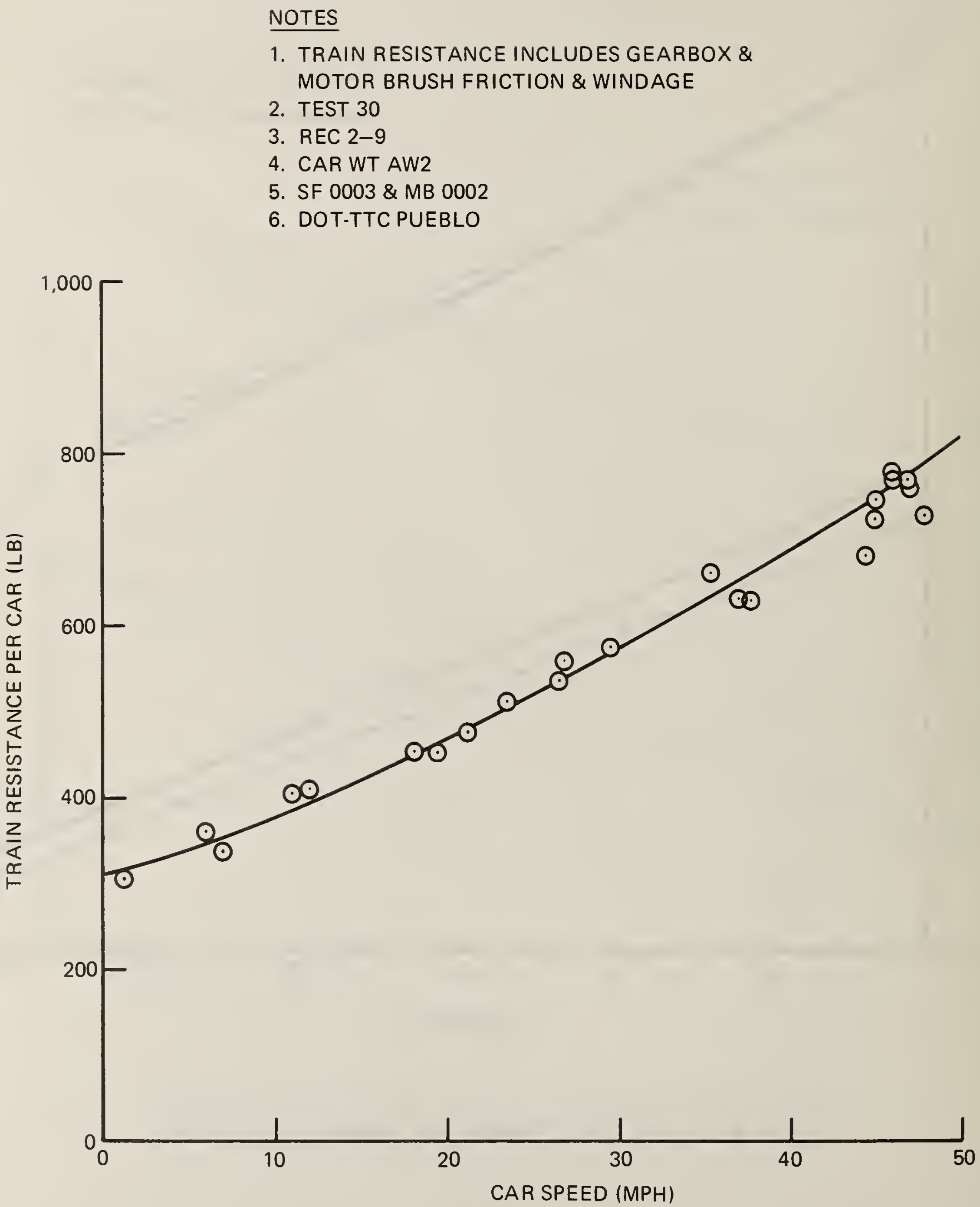


Figure 4–6. Drift Test, Two-Car Train

NOTES

1. MOTOR RPM = 71.98 x MPH
2. $HP = \dfrac{KW}{0.746}$
3. LOSSES QUOTED BY GARRETT AIRESEARCH

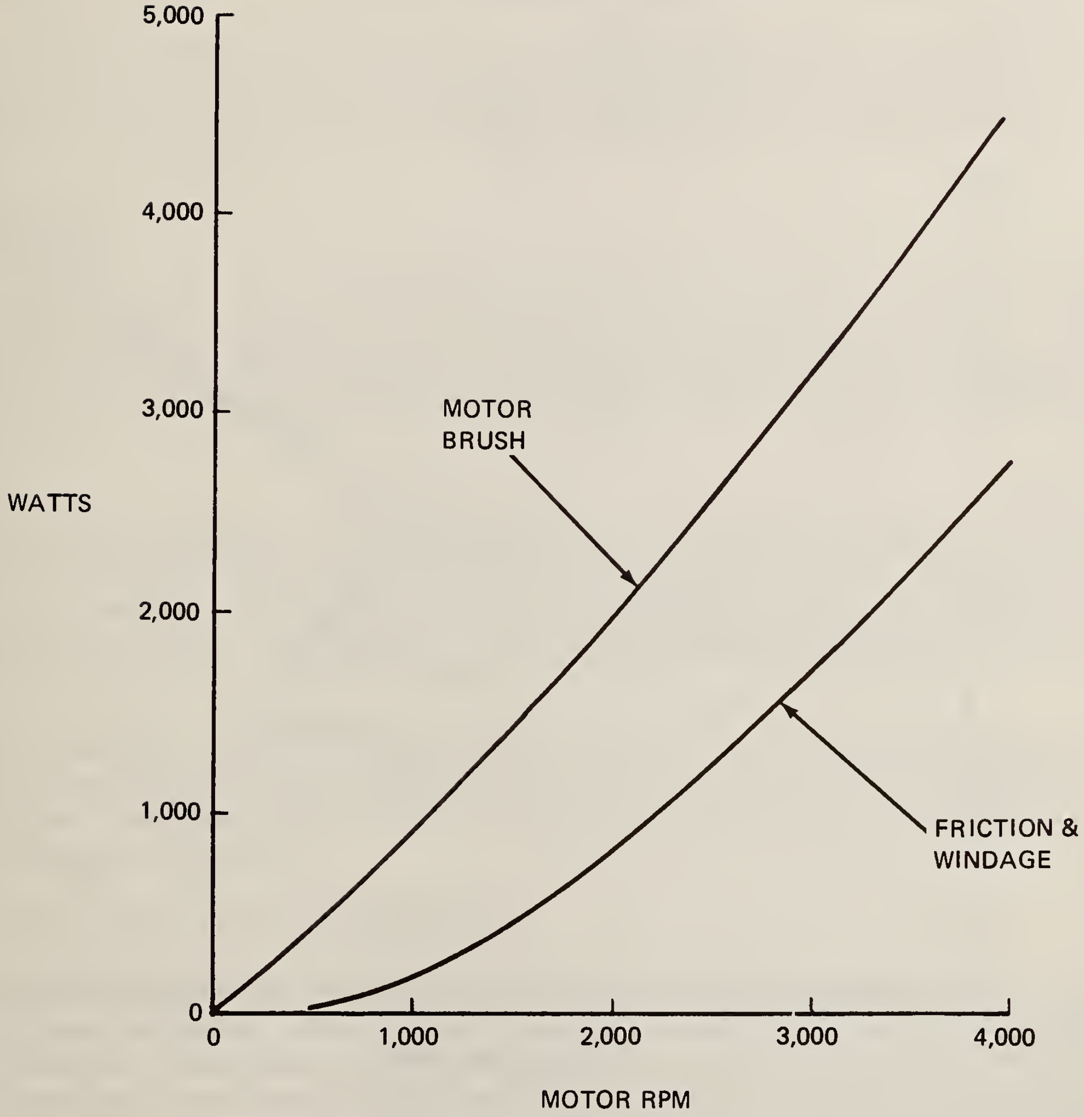


Figure 4–7. Motor Brush Friction and Windage Losses

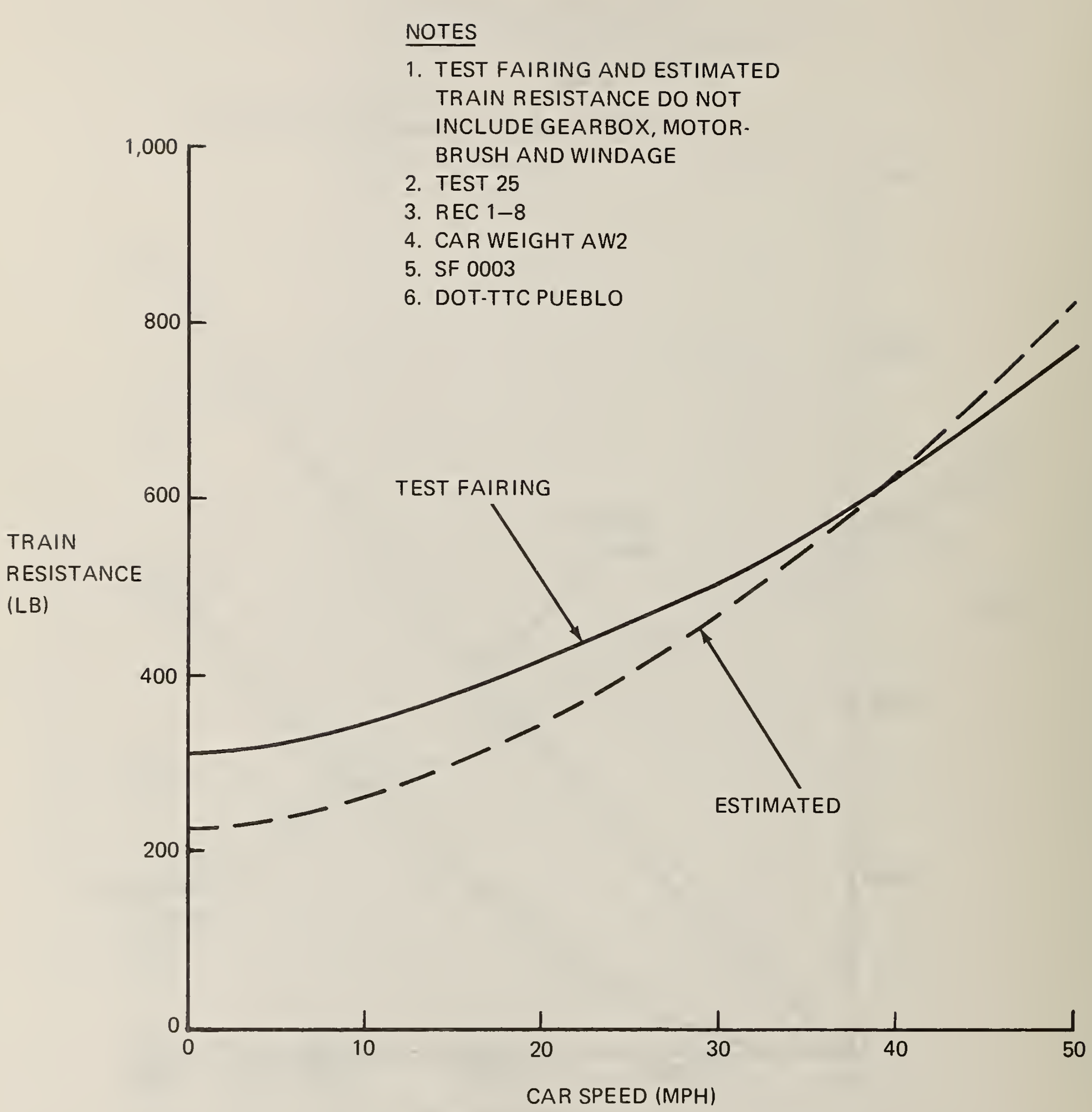


Figure 4–8. Train Resistance, Single Car

5. SPIN/SLIDE CONTROL SYSTEM TESTS

5.1 SUMMARY

Objective

The objective of the spin/slide protection system testing is to determine the efficiency of the SLRV spin/slide protection system throughout the speed range of the car in both drive and brake modes on wetted rail.

Procedure

The procedures used during the acceleration testing were those laid down in the General Vehicle Test Plan, Test Set P-2011-TT. During the deceleration testing the procedures were those specified in General Vehicle Test Plan, Test Set P-3011-TT and included both blended and friction only braking modes.

Test Sequence

Spin/slide testing was accomplished using car SF-0002 with initial speeds of from 20 to 50 mph for the braking and up to 45 mph for the acceleration tests. Testing was conducted with the car at the AW0 weight (69,130 pounds). As specified, the tests were conducted on both dry and wet rails (various levels of wetting agents were used to reach the reported wet condition).

Status

The tests were conducted in conjunction with the qualification testing of the SLRV at Pueblo, Colorado, in March 1976. Braking tests were conducted with full service friction only, full service blended, and partial blended braking. Continuous slides were achieved in full service only braking conditions. The slip/slide efficiency measured during the deceleration tests exceeded the system design goal of 75 percent.

Acceleration tests were conducted with full acceleration starting from zero car speed and attaining up to 45 mph car speed. However, spin conditions above base speed were not encountered. The slip/spin protection system performance exhibited during these tests exceeds the design goal of 40 percent.

5.2 ACCELERATION TEST DESCRIPTION

This section contains SLRV test data on the slip-spin system acceleration performance. The wheel slip-spin protection system is designed to detect and control wheels spins whether random or synchronous. The system is operative for all acceleration commands. Upon detection of a wheel spin during acceleration, wheel control is maintained by simultaneously removing the current to the series connected traction mono-motors on the end trucks, on a non-jerk-limited basis, until the spin is corrected. Following correction, tractive effort is automatically reapplied under jerk-limited control. The tests of the slip-spin acceleration performance are intended to show satisfactory system functional capability and efficiency.

The wheel slip-spin acceleration performance data was acquired in Tests 64 and 65 with SF-0002 car at AW0 car weight. These tests have been performed pursuant to General Vehicle Test Procedures, specific test set, SLRV-P-2011-TT. The testing was conducted at DOT TTC Pueblo, Colorado, during March 1976.

5.3 INSTRUMENTATION

The parameters instrumented and recorded during the slip/spin tests were the same as those recorded during the other performance testing. Tables 2-2 and 2-3 present the listing of instrumented data channels and the various locations of the recorded data. The axle speeds were used to identify the presence of spins/slides and the accelerometer peaks were used to define available adhesion levels. In acceleration testing, the velocity recorded on the center truck is taken as true velocity since it is unpowered.

5.4 TEST PROCEDURES

To acquire slip-spin acceleration performance data, 12 runs were conducted with full acceleration during Tests 64 and 65. Of these runs, four runs exhibit wheel spins, but only three runs contain wheel spins over a significant speed range from the initial start at zero speed through about base speed. However, an instrumentation malfunction reduced the number of runs that could be analyzed to only two (Run 31 of Test 64, and Run 22 of Test 65). Although testing was conducted up to 45 mph, wheel spin did not occur much beyond base speed. In view of the difficulty encountered in generating wheel spins at full acceleration, testing at partial acceleration was not conducted.

Further details of the slip-spin events are summarized in Table 5-1.

A concise description of the data reduction methodology for determining slip-spin efficiency follows. The slip-spin efficiency (η) is defined as:

$$\eta = \frac{(\bar{a}_a) \quad \text{Average car acceleration} \times 100}{(\bar{a}_m) \quad \text{Maximum average acceleration for the available adhesion}}$$

To determine the average car acceleration, the following expression is used:

$$(\bar{a}_a) = \frac{V_a^{\,2}}{2 \times S_a}$$

TABLE 5–1. SUMMARY OF SLIP-SPIN TEST RESULTS

Test No.	Run No.	Speed Range (mph)	Slip-Spin Efficiency (%)	Actual Distance Traveled (ft)	Minimum Theor Distance Traveled (ft)	Average Car Accel (mphps)	Average Peak Accel (mphps)
64	31	0-11.3	49.3	95.5	47.1	0.97	1.99
65	22	0-16.4	45.9	184.5	84.7	1.07	2.33

V_a is the velocity attained at the end of the acceleration run. For these tests, V_a is selected as the speed beyond which spins do not occur — about base speed. S_a is the distance the car travels in accelerating from an initial speed to V_a speed.

To determine S_a, the actual distance traveled during the acceleration run, the speed signal of one axle of the non-motored center truck is integrated numerically over the speed range from zero to V_a speed. The speed signals from the axles on the center truck represent true car speed during acceleration runs since they are unpowered and cannot spin.

To determine the maximum average acceleration which available adhesion will support, the following expression is used:

$$(\bar{a}_m) = \frac{V_a^2}{2 \times S_{100\%}}$$

$S_{100\%}$ represents a theoretical minimum distance to accelerate from zero speed to V_a speed, based on the peak acceleration rates exhibited during the acceleration run. The $S_{100\%}$ distance is computed by double numerical integration of the acceleration level defined by the locus of peak acceleration rates corresponding to maximum available adhesion.

A sample calculation using this methodology is shown in Table 5-2 for Test 64 Run 31. Also, time histories of the acceleration and axle speed for this event are shown in Figure 5-1. The V_a speed and locus of peak acceleration rates are illustrated.

The slip-spin efficiency is calculated to be 49.3 percent for Run 31 of Test 64, and 45.9 percent for Run 22 of Test 65 and exceeds the specification requirements (40 percent) by a margin of 23-15 percent. The SLRV slip-spin systems performance exceeds specification goals by at least 15 percent.

5.5 TEST DATA

The section of the SLRV Technical Specification that is applicable to wheel slip-spin acceleration performance is reproduced below:

> Slip-Spin Efficiency is defined as the average car deceleration or deceleration rate (mphps) expressed as a percentage of the rate which available adhesion is capable of supporting during any continuous sequence of the wheel slip-spin protection system. The efficiency of the Light Rail Vehicle wheel slip-spin system shall be at least 40 percent in acceleration and 75 percent in braking over the speed range between maximum and approximately 5 mph.

5.6 DECELERATION TEST DESCRIPTION

This section contains SLRV qualification test data on slip-slide deceleration performance. The SLRV wheel slip-slide protection system is designed to detect and control wheel slips whether random or synchronous. It is functional under all service braking commands but is inoperative during emergency braking conditions. Under detection of a wheel slip during braking, the

TABLE 5–2. SAMPLE CALCULATION, SLIP-SPIN SYSTEM PERFORMANCE (TEST 64, RUN 31, FULL ACCELERATION)

Accelerate from zero speed to V_a = 16.5 ft/sec (11.25 mph). Calculation for S_a: actual distance traveled based on the center truck wheel speed signal.

Time (sec)	V_{ave} (ft/sec)	S (ft)
0-1	2.5	2.5
1-2	4.5	4.5
2-3	6.	6.
3-4	7.5	7.5
4-5	8.5	8.5
5-6	10.5	10.5
6-7	11.5	11.5
7-8	13.5	13.5
8-9	14.5	14.5
9-10	16.5	16.5
	S_a =	95.5 ft

then, the average car acceleration is:

$$\bar{a}_a = \frac{(16.5)^2}{2x95.5} = 1.42 \text{ ft/sec}^2 \text{ (0.97 mphps)}$$

Calculation for $S_{100\%}$: minimum theoretical distance traveled from the acceleration record using the locus of peak rates

Time (sec)	a_{ave} (ft/sec^2)	V_1 (ft/sec)	V_2 (ft/sec)	V (ft/sec)	S (ft)
0-1	3.2	0	3.2	1.6	1.6
1-2	3.1	3.2	6.3	4.75	4.75
2-3	3.0	6.3	9.3	7.8	7.8
3-4	2.9	9.3	12.2	10.75	10.75
4-5	2.8	12.2	15.0	13.6	13.6
5-5.545	2.746	15.0	16.5	15.75	8.58
				$S_{100\%}$ =	47.08 ft

then the average peak acceleration is:

$$\bar{a}_m = \frac{(16.5)2}{2x47.1} = 2.89 \text{ ft/sec}^2 \text{ (1.97 mphps)}$$

Hence the slip-spin efficiency is:

$$\eta = \frac{(\bar{a}_a)}{\bar{a}_m} = \frac{1.425}{2.89} = 49.3\%$$

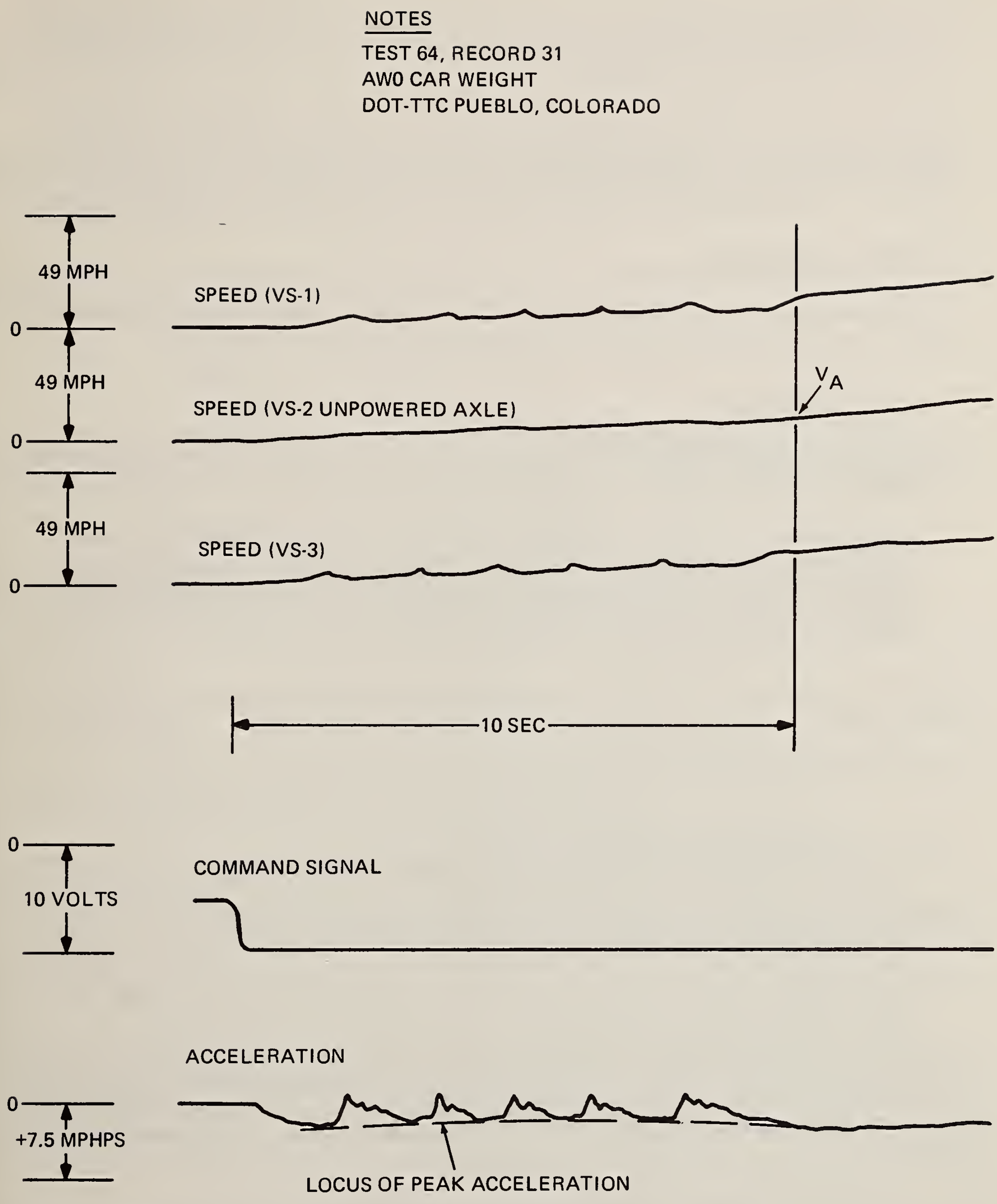


Figure 5—1. SLRV Slip-Spin Acceleration Performance

dynamic braking effort is eliminated and wheel slip control is maintained by the friction brake only, on a per-truck basis. Detection is achieved on a per-truck basis for the motored trucks and on a per-axle basis for the center truck.

The wheel slip-slide deceleration performance data was obtained in tests 63, 64, and 65 with SF0002 car at AW0 car weight. The tests have been performed in accordance with Boeing Document D334-10059-1, Standard Light Rail Vehicle Test Procedures, specific test set: SLRV-P-3100-TT. The testing was conducted at DOT TTC Pueblo, Colorado, during March 1976.

5.7 INSTRUMENTATION

The parameters instrumented and recorded during the slip/spin braking tests are as recorded for the acceleration tests and other performance testing (see Tables 2-2 and 2-3).

5.8 TEST PROCEDURE

The portion of the SLRV Technical Specification that pertains to wheel slip-slide deceleration performance is restated below.

> Slip-spin efficiency is defined as the average car deceleration or acceleration rate (mphps) expressed as a percentage of the rate which available adhesion is capable of supporting during any continuous sequence of the wheel slip-spin protection system. The efficiency of the Light Rail Vehicle wheel slip-spin system shall be at least 40 percent in acceleration and 75 percent in braking over the speed range between maximum and approximately 5 mph

A brief description of the data reduction methodology employed to determine slip-slide efficiency follows.

The slip-slide efficiency (η) is defined as:

$$\eta = \frac{(\bar{a}_b) \text{ Average car acceleration x 100}}{(\bar{a}_m) \text{ Maximum average acceleration for the available adhesion}}$$

To determine the average car acceleration, the following expression is used:

$$(\bar{a}_b) = \frac{V_B{}^2}{2 \times S_B}$$

V_B is the velocity at the instant that the first wheel slip occurs and S_B is the stopping distance from that same effective *brake* point. The velocity V_B is read directly from the output of the oscillograph instrumentation system based on the wheel speed signals from either axle of the center truck.

To determine S_B, the stopping distance from the instant that the first wheel slip occurs or effective *brake* distance, the transition distance from the *brake entry* point to the *brake* point is subtracted from the measured stopping distance S_D.

Car stopping distance S_D is measured by means of a surveyor's chain from the point of initial *brake entry*, which is prior to the instant that the first wheel slip occurs, to the point where the car comes to rest. The point of initial *brake entry* corresponds to the initiation of blended or friction only braking commands.

The transition distance is obtained from the output of the oscillograph instrumentation system as the product of the average of the *brake entry* and *brake* speeds and the transition time interval between these events.

To determine the maximum average acceleration which available adhesion will support, the following expression is used:

$$(\bar{a}_m) = \frac{V_B^2}{2 \times S_{100\%}}$$

$S_{100\%}$ represents a theoretical minimum stopping distance from the *brake* point based on the peak deceleration rates exhibited during the braking event. The $S_{100\%}$ distance is computed by double numerical integration of the deceleration level defined by the locus of peak deceleration rates corresponding to maximum available adhesion.

A sample calculation using this methodology is shown in Table 5-3 for Test 64, Run 15. Also, time histories of the acceleration and axle speed for this event are shown in Figure 5-2. The *brake entry* point, *brake* point, *transition* interval, and locus of peak deceleration rates are illustrated.

5.9 TEST DATA

The summary shown in Table 5-4 illustrates that the slip-slide performance requirements are satisfied, since the minimum recorded efficiency is 76.3 percent.

The results displayed in Table 5-4 represent the extremes encountered from among all the test runs for which slides were obtained. In some cases, slides were not developed continuously throughout the braking event and may have occurred for one truck only. As a result, analysis of this data yields high slip-slide system efficiencies. An example of this is Test 64 Run 22 where at 22 mph the slip-slide efficiency with only one slide on the A-end truck is 90.5 percent. For the substantial number of tests where continuous slides are encountered throughout the braking event on all trucks, a slip-slide efficiency of 76.3 to 81.1 percent for full service blended braking and 78 to 87.5 percent for full service friction only braking is achieved over the surveyed speed range of 20 to 50 mph. Substantially, all slides were developed randomly; however, two synchronous slides were experienced in Test 63 Run 16, a full service friction only braking condition. For this test condition with synchronous slides, the slip-slide efficiency is 82.5 percent. Further slip-slide test results are reported in Tables 5-5 and 5-6.

Several tests were conducted using partial blended braking modes (75, 50, and 25 percent of full service blended braking) but wheel slides did not occur.

TABLE 5–3. SAMPLE CALCULATION SLRV SLIP-SLIDE PERFORMANCE (TEST 64 RUN 15 FULL SERVICE BLENDED BRAKING)

Measured Stopping Distance, S_D = 1,125 ft

V_{3e} = 73.33 ft/sec

V_B = 72.16 ft/sec

Transition Time = 0.6997 sec

Transition Distance = 0.6997 x 1/2 (73.33 + 72.16) = 50.9 ft

Stopping Distance from "brake" point = 1125–50.9 = 1074.1 ft

Average Car Deceleration:

$$(\bar{a}_a) = \frac{(72.16)^2}{2 \times 10.74.1} = 2.42 \text{ ft/sec } (1.65 \text{ mphps})$$

Average Demonstrated Adhesion,

$$\mu_B = \frac{2.42}{32.2} = 0.075$$

Calculation for $S_{100\%}$ and $\bar{a}_m$, Max Average Deceleration that available adhesion will support

Time (sec)	Decel (ft/sec)	V_1 (ft/sec)	V_2 (ft/sec)	$\bar{V}$ (ft/sec)	S (ft)
0-11	2.9	72.16	40.26	56.2	618.2
11-12	3.0	40.26	37.26	38.76	38.76
12-13	3.05	37.26	34.21	35.74	35.74
13-14	3.15	34.21	31.06	32.64	32.64
14-15	3.30	31.06	27.76	29.41	29.41
15-16	3.40	27.76	24.36	26.06	26.06
16-17	3.50	24.36	20.86	22.61	22.61
17-18	3.60	20.86	17.26	19.06	19.06
18-19	3.60	17.26	13.67	15.47	15.47
19-20	3.60	13.67	10.06	11.87	11.87
20-21	3.70	10.06	6.36	8.21	8.21
21-22	3.80	6.36	2.56	4.46	4.46
22-23	3.90	2.56	0	1.28	1.28
				$S_{100\%}$ =	863.77 ft

Max Average Deceleration

$$\bar{a}_m = \frac{(72.16)^2}{2 \times 863.77} = 3.01 \text{ ft/sec } (2.06 \text{ mphps})$$

Max Available Adhesion $= \dfrac{3.01}{32.2} = 0.094$

Slip-Slide Efficiency, η $= \dfrac{2.42 \times 100}{3.01} = 80.4$ percent

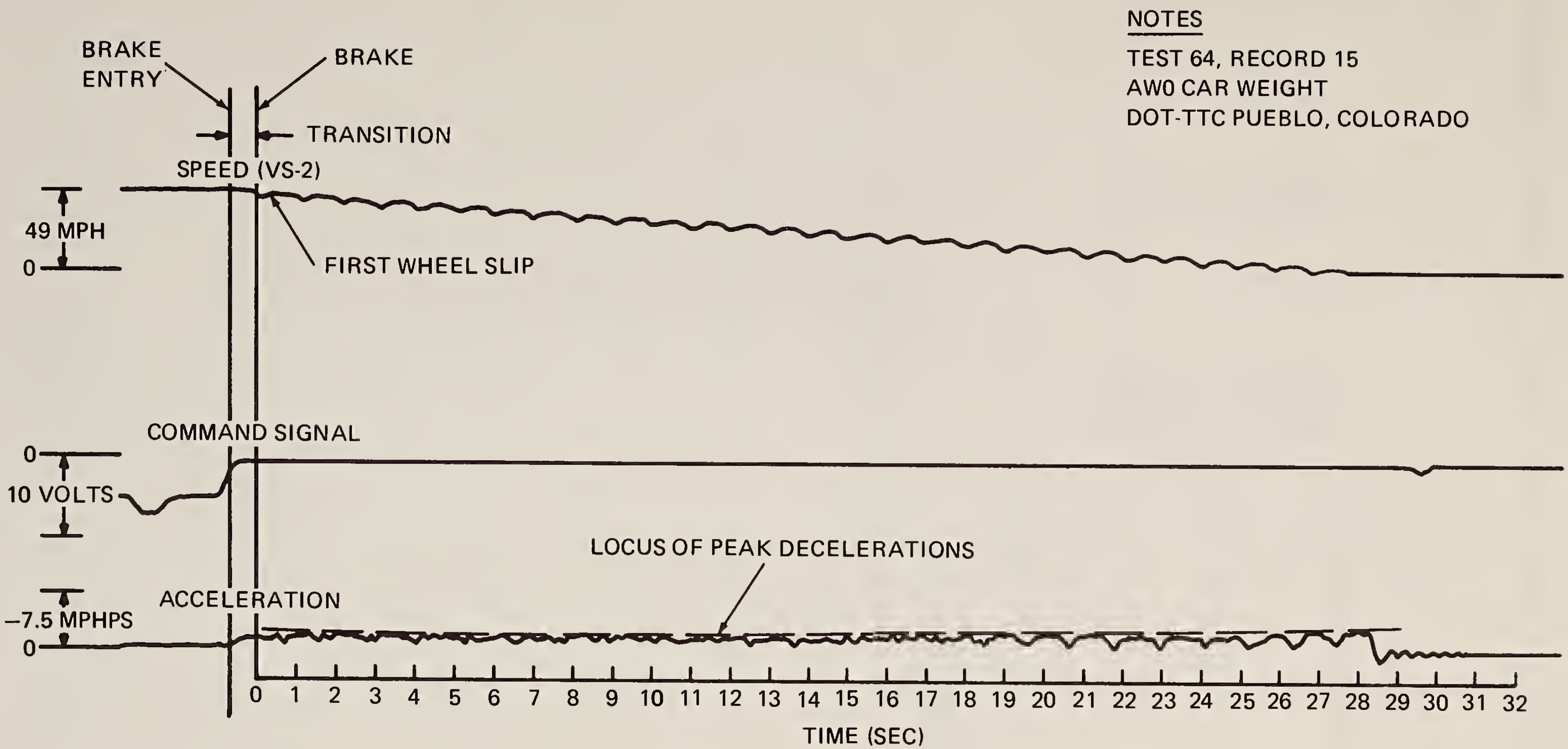


Figure 5–2. SLRV Slip-Slide Deceleration Performance

TABLE 5–4. SUMMARY OF SLIP-SLIDE SYSTEM EFFICIENCY IN BRAKING

Item		SLRV Spec	Test Result
Braking Mode			
Full-Service Blended:	20 mph	75%	76.3 – 90.5
	30 mph	75%	77.7 – 82.8
	40 mph	75%	81.1 – 87.2
	50 mph	75%	80.4 – 85.4
Full-Service Friction Only:	20 mph	75%	87.5 – 95
	30 mph	75%	80.5 – 88.4
	40 mph	75%	78.5 – 85.9
	50 mph	75%	78.0 – 86.0

5.10 CONCLUSION

The SLRV slip-slide system performance exceeds specification goals.

TABLE 5–5. SLIP/SLIDE TEST RESULTS, BLENDED BRAKING

Test No.	Test Speed (mph)	Effic	μ Avail.	μ Demo	Trans Time (sec)	S_T Trans Dist (ft)	V_E (ft/sec)	V_B (ft/sec)	S_B (ft)	$S_{100\%}$ (ft)	S_P Measured (ft)	Comments
64-14	50	81.2	0.119	0.097	0.947	67.78	72.6	70.54	797.2	647.5	865	A & B Truck, No Slides Mid Stop
64-15	50	80.4	0.94	0.075	0.699	50.9	73.3	72.2	1074.1	863.8	1125	
64-16	30	79.7	0.100	0.080	0.58	24.6	42.8	41.9	340.4	271.2	365	A Truck, No Slides Last 2 sec
64-17	30	77.7	0.113	0.088	0.548	23.2	42.8	41.9	310.8	241.5	334	
64-18	30	82.8	0.118	0.098	0.757	32.2	42.8	42.2	281.8	233.3	314	A Truck, No Slides Last 3 sec
64-19	30	80.8	0.118	0.096	0.639	27.3	43.3	42.2	288.7	233.3	316	A Truck, No Slides Last 3 sec
64-20	30	80.9	0.117	0.095	0.731	30.3	41.4	41.4	274.7	226.5	310	A Truck, No Slides Last 3.5 sec
64-21	20	76.3	0.106	0.081	0.626	16.9	27.3	26.8	138.1	105.4	155	
64-22	20	90.5	0.122	0.110	0.509	14.4	28.4	28.3	112.6	102.0	127	One Slide Only, A Truck
64-23	20	81.5	0.113	0.092	0.548	15.7	29.0	28.3	135.3	110.3	151	
64-24	20	78.0	0.115	0.089	0.60	16.9	28.3	27.9	135.0	105.4	152	
64-25	20	78.9	0.113	0.089	0.516	15.0	29.3	29.0	147.0	116.0	162	
64-34	50	83.8	0.122	0.102	0.626	44.3	71.8	69.6	734.7	616.1	779	A Truck, One Slide Only
64-35	50	85.4	0.114	0.098	0.718	51.1	71.8	70.5	788.9	673.8	840	A Truck, One Slide Only
64-36	50	81.7	0.117	0.096	0.621	44.2	71.8	70.5	805.8	658.5	850	A Truck, No Slides Last 15 sec
64-37	40	81.1	0.120	0.097	0.72	40.5	56.1	55.7	496.5	402.9	537	A Truck, 2 sec Lockup
65-10	40	87.2	0.104	0.090	0.88	52.5	60	59.3	602.5	525.3	655	
65-11	40	80.4	0.104	0.084	0.71	42.3	59.8	59.5	654.7	525.6	697	
65-12	40	80.7	0.102	0.082	0.80	47.8	60	59.5	672.2	542	720	
65-13	40	84.8	0.097	0.082	0.68	40	59.5	59.0	656	556	696	
65-14	40	82.5	0.096	0.080	0.56	33.5	60	59.5	692.5	571	726	

TABLE 5–6. SLIP/SLIDE TEST RESULTS, FRICTION BRAKES ONLY

Test No.	Test Speed (mph)	Effic	μ Avail	μ Demo	Trans Time (sec)	S_T Trans Dist (ft)	V_E (ft/sec)	V_B (ft/sec)	S_B (ft)	$S_{100\%}$ (ft)	S_P Measured (ft)	Comments
63-6	30	88.4	0.113	0.100	1.0	45.2	46	44	301	266	346	Center Truck Slide Only
63-7	30	80.5	0.095	0.076	1.14	50.2	44	44	393	316	443	
63-8	40	78.5	0.095	0.074	0.78	35.3	46.2	44	406	319	441	
63-9	40	81	0.094	0.076	1.15	68.6	60.1	59.3	716	580	785	
63-10	50	86	0.084	0.074	1.04	72.7	60.5	60.1	762	658	825	
63-11	50	84.5	0.087	0.074	0.58	42.2	71.9	71.9	1079	916	1121.5	
63-12	50	84.6	0.087	0.074	0.88	65.9	74.6	74.0	1146	970	1212	
63-13	50	78	0.092	0.071	0.83	62.2	74.8	74.0	1178	926	1249.5	
63-14	50	89.9	0.120	0.108	1.2	83.9	72.7	71.8	744	664	827.5	Center Truck Only, Slide First 12 sec
63-16	50	82.5	0.086	0.071	0.87	62.3	71.9	71.4	1109	915	1171	Sync Slide, 1 and 12 sec
63-17	50	82.4	0.086	0.071	0.73	52.5	71.9	71.9	1122	925	1175	
63-18	50	82.5	0.093	0.077	0.52	37.7	72.5	71.9	1041	860	1079	
63-19	40	85.1	0.101	0.086	1.0	58.9	57	58.7	616	527	675	
63-20	40	85.9	0.113	0.097	0.89	53	60.1	57	557	478	610	
63-21	20	79.4	0.143	0.114	0.89	27	30.8	30	123	98	150	
64-10	20	87.5	0.107	0.093	0.70	21	29.3	28.9	139	121	160	
64-11	20	93.5	0.125	0.118	0.84	26	31.4	30.4	122	114	148	A Truck, One Slide
64-12	20	93.6	0.114	0.106	0.60	18.1	30.9	30.9	139	130	158	
64-13	20	95	0.116	0.111	0.60	17.4	29.8	29.8	124	118	141	A Truck, Two Slides

6. POWER CONSUMPTION TESTS

6.1 SUMMARY

Objective

The objective of the power consumption testing is to determine the SLRV energy consumption while operating on a sample service route at a defined level of schedule performance. The tests are designed to provide a measure of car schedule performance, power consumption, and overall traction system efficiency.

Procedure

General Vehicle Test Plan PC-5011-TT baseline test procedure was used to obtain energy consumed during the duty cycle testing.

Test Sequence

Primary duty cycle testing was conducted using car SF0003 as follows:

Single Car (AW2) Blended Braking	– 575V Nominal	– Test 38, Record 3
	– 480V Nominal	– Test 36, Record 16
	– 750V Nominal	– Test 37, Record 4

Single Car (AW2) Friction Brakes Only – 575V Nominal – Test 38, Record 4

Status

Test data were obtained from a sequence of vehicle excursions simultating a scheduled route having 93 station stops and which also simulated both surface and subway operation at maximum speeds of 26 mph and 50 mph, respectively.

A vehicle loaded to the AW2 configuration (82,500 pounds) was used and the energy consumed during the duty cycle was recorded manually from an instrument channel which combined line volts, line amps, and time with a digital counter (0.1 kw-hr) as readout.

Undercar equipment temperatures were also recorded during the synthetic route tests.

6.2 TEST DESCRIPTION

The simulated N-line duty cycle testing was performed on the DOT TTC facility in Pueblo, Colorado, following the SLRV-PC-5011-TT procedure. The 1-hour duty cycle utilizing a nominal 575 line volts was accomplished during Test 38, Record 3, for full service blended braking and again during Test 38, Record 4, for friction only braking on June 25, 1976.

A two-hour blended braking duty cycle was performed with the line voltage adjusted to provide a maximum of 750 volts during Test 37, Record 4, on June 24, 1976. Testing with a minimum of 475 volts was accomplished during Test 36, Record 6, on June 23, 1976.

The simulated N-line duty cycle was developed for the DOT TTC testing based on the Garrett AiResearch simulated N-line test reported in the Combined Systems Laboratory Test document 74-10394, June 2, 1974. The effect of grades was included in the AiResearch simulation, whereas the DOT TTC simulation is mostly level tangent track.

6.3 INSTRUMENTATION

The instrumentation parameters recorded during energy consumption testing consisted of the basic performance parameters plus one channel combining line volts, line amps, and time with a digital counter (0.1 kw-hr) as quick-look readout.

In addition, undercar equipment temperatures were recorded in 20 locations.

6.4 TEST PROCEDURES

During the period January 20, 1976, through February 13, 1976, the following air flow measurements were taken in plane with the brake gride:

With the SLRV A end leading, the relative airflow

- one foot in front of the brake grid is 60 to 70 percent of car velocity
- one foot to the rear of the brake grid, the airflow is approximately 50 percent of car velocity at all speeds between 0 and 50 mph

With the SLRV B end leading, the relative airflow

- one foot in front of the brake grid is 90 to 95 percent of car velocity
- one foot to the rear of the brake grid the airflow is approximately 50 percent of the car velocity at all speeds between 0 and 50 mph

The manner in which the N-line duty cycle simulation was performed is presented in Table 6-1 and includes the track profile over which the duty cycle was performed.

6.5 TEST DATA

A summary of the one-hour simulated N-line duty cycle, with blended brakes, is presented in Table 6-2 and includes the number of surface stops and number of subway stops, maximum speeds for the surface and subway runs, station dwell times, trip time and energy consumption. The Boeing Vertol prediction of the energy consumption utilizing the DOT TTC track profile is presented for comparison with the Test 38, Record 3 energy consumption. The Boeing Vertol prediction provided an energy consumption of 9.97 kw-hr/car mile over a total distance of 13.93 miles, whereas the energy consumption obtained from Test 38, Record 3 was 10.21 kw-hr/car mile for a total distance of 14.49 miles. Correcting the test data for a total distance of 13.39 miles, for a comparison with the predicted value, yields an energy consumption of 9.81 kw-hr/car mile. This compares to the Boeing predicted kw-hr/car mile of 9.97 for the test conditions.

The effect on energy consumption due to performing the duty cycle at the maximum line voltage of 750 volts and the minimum line voltage of 480 volts is presented in Table 6-3. The

TABLE 6–1. SLRV DUTY CYCLE SIMULATION

TEST DESCRIPTION
Start duty cycle at station 285 +00; run vehicle clockwise (N); end clockwise operation at station 380 +00 (catenary starts at station 279 +00, ends at 385 +00)
38 Station Stops, Maximum Speed 26 mph 19 Clockwise Direction — Start at station 285; accelerate to 26 mph; initiate braking to complete start-to-stop run within 500 feet; end 19th stop at station 380. 19 Counterclockwise Direction — Start at station 380; end 19th stop at station 285.
12 Station Stops, Maximum Speed 50 mph 3 Clockwise Direction — Start at station 285, accelerate to 50 mph; cruise approximately 10 seconds at 50 mph; initiate braking to complete start-to-stop run within 3000 feet; end 3rd stop at station 375 +00. 3 Counterclockwise Direction — Start at station 375 +00; end 3rd stop at station 285 +00. Repeat clockwise and counterclockwise runs to complete 12 stops from 50 mph; end 12th stop at station 285 +00.
43 Station Stops, Maximum Speed 26 mph 19 Clockwise Direction — Start at station 285; end 19th stop at station 380. 19 Counterclockwise Direction — Start at station 380, end 19th stop at station 285. 5 Clockwise Direction — Start at station 285; end 5th stop (and duty cycle) at station 310 +00.

Notes:

1. Station Dwells: 8.5 sec at 26 mph Station Stop
   15.0 sec at 50 mph Station Stop

2. Brake Marks for 26 mph Entry Speed: 175 ft from Station Stop
   Brake Marks for 50 mph Entry Speed: 600 ft from Station Stop

3. Station stops were marked by white stakes, brake marks for 26 mph stops by red stakes, and brake marks for 50 mph stops by yellow stakes.

4. Test Set Number: SLRV-PC-5011 TT

TABLE 6–1. Continued

STATION STOPS AND BRAKE MARKS – 26-MPH STOPS					
CLOCKWISE (NORTH)			COUNTERCLOCKWISE (SOUTH)		
	Station	Brake Marks		Station	Brake Marks
Start	28500		Start	38000	
	28825	*		37675	*
Stop 1 –	29000		Stop 1 –	37500	
	29325	*		37175	*
Stop 2 –	29500		Stop 2 –	37000	
	29825	*		36675	*
Stop 3 –	30000		Stop 3 –	36500	
	30325	*		36175	*
Stop 4 –	30500		Stop 4 –	36000	
	30825	*		35675	*
Stop 5 –	31000		Stop 5 –	35500	
	31325	*		35175	*
Stop 6 –	31500		Stop 6 –	35000	
	31825	*		34675	*
Stop 7 –	32000		Stop 7 –	34500	
	32325	*		34175	*
Stop 8 –	32500		Stop 8 –	34000	
	32825	*		33675	*
Stop 9 –	33000		Stop 9 –	33500	
	33325	*		33175	*
Stop 10 –	33500		Stop 10 –	33000	
	33825	*		32675	*
Stop 11 –	34000		Stop 11 –	32500	
	34325	*		32175	*
Stop 12 –	34500		Stop 12 –	32000	
	34825	*		31675	*
Stop 13 –	35000		Stop 13 –	31500	
	35325	*		31175	*
Stop 14 –	35500		Stop 14 –	31000	
	35825	*		30675	*
Stop 15 –	36000		Stop 15 –	30500	
	36325	*		30175	*
Stop 16 –	36500		Stop 16 –	30000	
	36825	*		29675	*
Stop 17 –	37000		Stop 17 –	29500	
	37325	*		29175	*
Stop 18 –	37500		Stop 18 –	29000	
	37825	*		28675	*
Stop 19 –	38000		Stop 19 –	28500	

TABLE 6–1. Continued

STATION STOPS AND BRAKE MARKS – 50-MPH STOPS					
CLOCKWISE (NORTH)			COUNTERCLOCKWISE (SOUTH)		
	Station	Brake Marks		Station	Brake Marks
Start	28500		Start	37500	
	30900	*		35100	*
Stop 1 –	31500		Stop 1 –	34500	
	33900	*		32100	*
Stop 2 –	34500		Stop 2 –	31500	
	36900	*		29100	*
Stop 3 –	37500		Stop 3 –	28500	

TRACK PROFILE			
North	Station	Grade (%)	Curve (deg)
Start Test Section	28500	+0.8497	1°30′
	29700	0.0	0.0
	34000	+0.6883	0.0
End Test Section	38000	+0.6883	0.0

TABLE 6–2. SUMMARY OF SIMULATED N-LINE DUTY CYCLE ON TTC TRACK PUEBLO, SINGLE CAR, AW2 CAR WEIGHT

	SLRV Test 38 Rec 3 Simulated N-Line TTC Track Pueblo	Boeing Vertol Prediction Simulated N-Line TTC Track
Surface Run No.	81	81
Maximum Speed (mph)	26	26
Station Dwell (sec)	8.5	9
Subway and Tunnel Run No.	12	12
Maximum Speed (mph)	50	50
Station Dwell (sec)	15	9
Total Distance (mi)	14.49	13.93
Total Dwell Time (sec)	868	837
Round Trip Time (mph)	58.17	52.94
Average Speed (mph)	14.9	15.8
Energy Consumption (kw-hr/car mile)	9.81[1]	9.97

Notes:

1. Test data corrected for total distance of 13.93 miles for comparison with Boeing Vertol prediction.
2. Boeing Vertol prediction for actual N-line profile is 11.68 kw-hr/car mile.
3. Garrett Airesearch Combined Systems Laboratory Test Report (74-10394, 2 July 1974) simulated N-line test results for energy consumption is 11.92 kw-hr/car mile.

TABLE 6–3. EFFECT ON KILOWATT-HOUR ENERGY CONSUMPTION DUE TO LINE VOLTAGE VARIATION

AW2, Simulated N-Line Duty Cycle at Pueblo TTC

Test/Rec	Type Duty Cycle	Line Voltage Initial	Line Voltage Drop at Base Speed	Station Stops	Time (sec)	Distance (miles)	Kw Hr	Kw-Hr / Car Mile
38/3	Blended Brake	630	560	93	3490	14.49	148	10.21
		(Nominal 575)						
38/4	Friction Brake	630	560	93	3558	14.49	152	10.49
37/4	Blended Brake	740	655	93	3720	14.49	159	10.97
		(Max Volt)		186	7154	28.98	323	22.29
36/6	Blended Brake	540	475	93	3481	14.49	137	9.45
		(Min Volt)		186	6950	28.98	279	19.25

maximum/minimum line voltage duty cycle station stops were increased to 186, rather than the 93 N-line stops, for a total running time of close to two hours. However, data are also presented at the end of the 93rd stop for comparison with the 1-hour duty cycle at the nominal 575 volts. The summary of the effect on energy consumption due to line voltage variation includes the following: type of duty cycle (blended or friction braking), the drop from the initial line voltage as the car accelerates to base speed, stations stops, trip time, distance, kw-hr, and kw-hr/car mile. A graphical presentation is also included in Figure 6-1 for a visual portrayal of the almost linear increase in energy consumption with increasing line voltage.

The undercar equipment temperatures are presented in Table 6-4 for the 2-hour duty cycles utilizing maximum and minimum line voltage and the two 1-hour duty cycles for blended and friction braking. An automatic temperature recorder, with a maximum capability of 500^{O}F, was used to monitor 18 thermocouples located on the underside, inside, and on top of the vehicle, as shown in Figure 6-2. The temperature data presented are the initial and maximum temperatures reached during the simulted N-line duty cycles.

Figure 6-3 presents the temperatures reached on the ground brush heat shield on the center truck during the blended brake duty cycle, Test 38, Record 3, and on the end truck during the friction brake duty cycle, Test 38, Record 4. This temperature was recorded manually utilizing a meter, since it was expected that the temperature on the end truck would exceed 500^{O}F during the friction brake duty cycle; however, as shown in Figure 6-3 the maximum temperature was 410^{O}F.

An oscillograph time history of line current is provided in Figure 6-4 for a typical station-to-station run, top speed 26 mph. The average line current draw was 738 amps during acceleration and 27 amps during blended braking.

The corrected value of 9.81 kw-hr/car mile obtained during the simulted N-line duty cycle at the DOT TTC facility agreed closely with the Boeing Vertol prediction of 9.97 kw-hr/car mile.

As a result of the duty cycle testing the level of confidence in the Boeing Vertol prediction of 11.68 kw-hr/car mile for the actual N-line duty cycle has been greatly increased. The Boeing Vertol prediction is slightly lower than the Garrett AiResearch prediction of 11.92 kw-hr/car mile.

The rms armature current for the simulated N-line duty cycle on the DOT TTC facility at Pueblo was calculated from data obtained using a meter similar to the kw-hr meter providing test results in amp^2-hr. A value of 255 amp^2-hr was recorded during the 1-hour blended braking duty cycle, Test 38 Record 3, providing an rms armature current of 513 amp. The Boeing Vertol prediction of an rms armature current of 620 amp was determined using the actual N-line profile. Therefore, no comparison is being made for the rms armature current since the test result of 513 amp does not include grade effect.

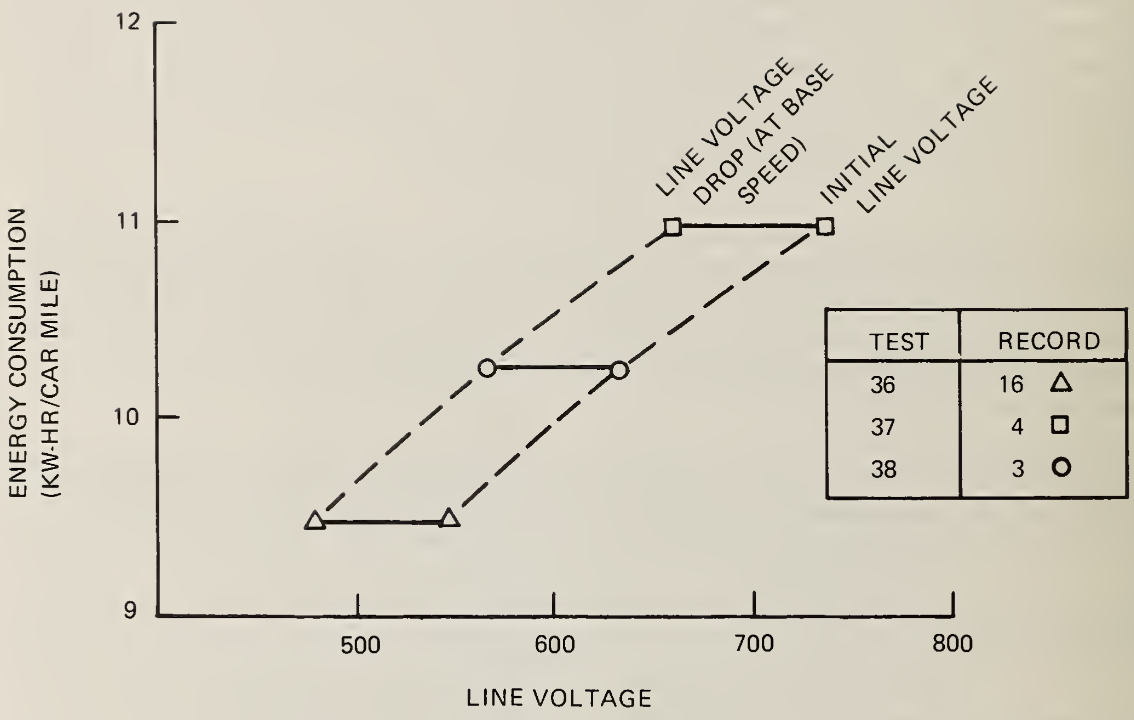
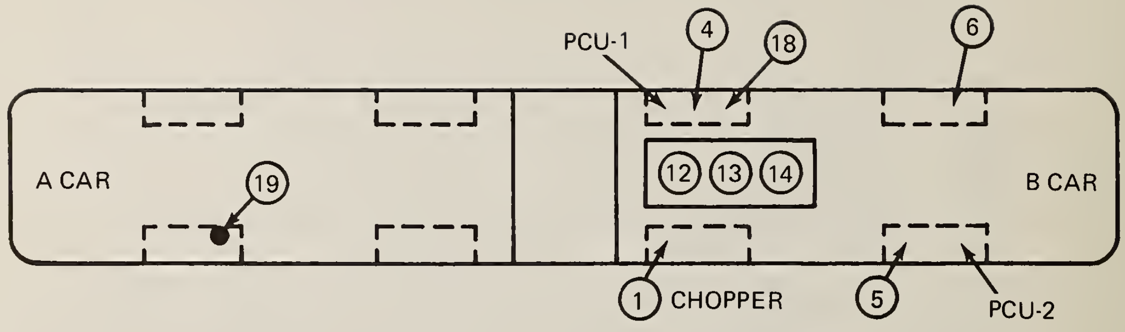


Figure 6–1. Kilowatt-Hours/Car Mile Comparison for 93 Station Stops, 14.49 Miles

TABLE 6–4. SUMMARY OF UNDERCAR EQUIPMENT TEMPERATURES

Location	Channel Number	Temperature (°F)							
		Two-Hour Duty Cycle Blended Brakes				One-Hour Duty Cycle			
		Test 36 Rec 16 Minimum Line Volt (480V)		Test 37 Rec 4 Minimum Line Volt (750V)		Blended Brakes Test 38 Rec 3 Line Volt 575V		Friction Brake Test 38 Rec 4 Line Volt 575 V	
		Initial Temp	Max Temp	Initial Temp	Max Temp	Initial Temp	Max Temp	Initial Temp	Max Temp
Chopper Box – Outlet Air	1	64	95	96	102	88	107	103	102
Traction Motor – Outlet Air	2	80	127	89	138	85	129	123	143
Traction Motor Frame	3	80	129	82	131	78	123	129	127
PCU-1 Outside Air	4	80	103	94	114	88	111	111	113
PCU-2 Outside Air	5	65	88	87	105	82	107	102	104
LVPS	6	70	95	83	100	82	103	102	102
Input Reactor	7	70	170	81	161	81	161	133	157
Smoothing Reactor	8	65	135	82	143	78	130	119	133
Compressor Air	9	80	101	100	123	100	120	111	111
Brake Resistor	12	60	125	85	163	85	160	86	96
On Bottom of	13	58	134	86	157	86	142	89	96
Heat Shield	14	56	135	88	157	88	148	92	97
Transmission Oil Drain Plug	15	95	199	122	215	108	185	175	197
Ambient Air Under Car	16	59	83	83	97	79	103	95	97
B End Traction Mtr Blower Frame	17	69	93	87	106	83	105	98	106
Filter Cap on A1 Mod Assy (PCU-1)	18	70	98	86	102	83	103	102	102
Wire Bundle in LRN – 329	19	88	93	113	133	92	115	107	127
Ambient Air Under Car	20	59	82	83	99	80	107	85	98



TOP VIEW

BOTTOM VIEW

Figure 6–2. Thermocouple Locations

NOTES

TEST	RECORD	TYPE BRAKING	TRUCK	
38	3	BLENDED	CENTER	⊙
38	4	FRICTION	"B" END	△

NORTHBOUND A END DRIVES

SOUTHBOUND B END DRIVES

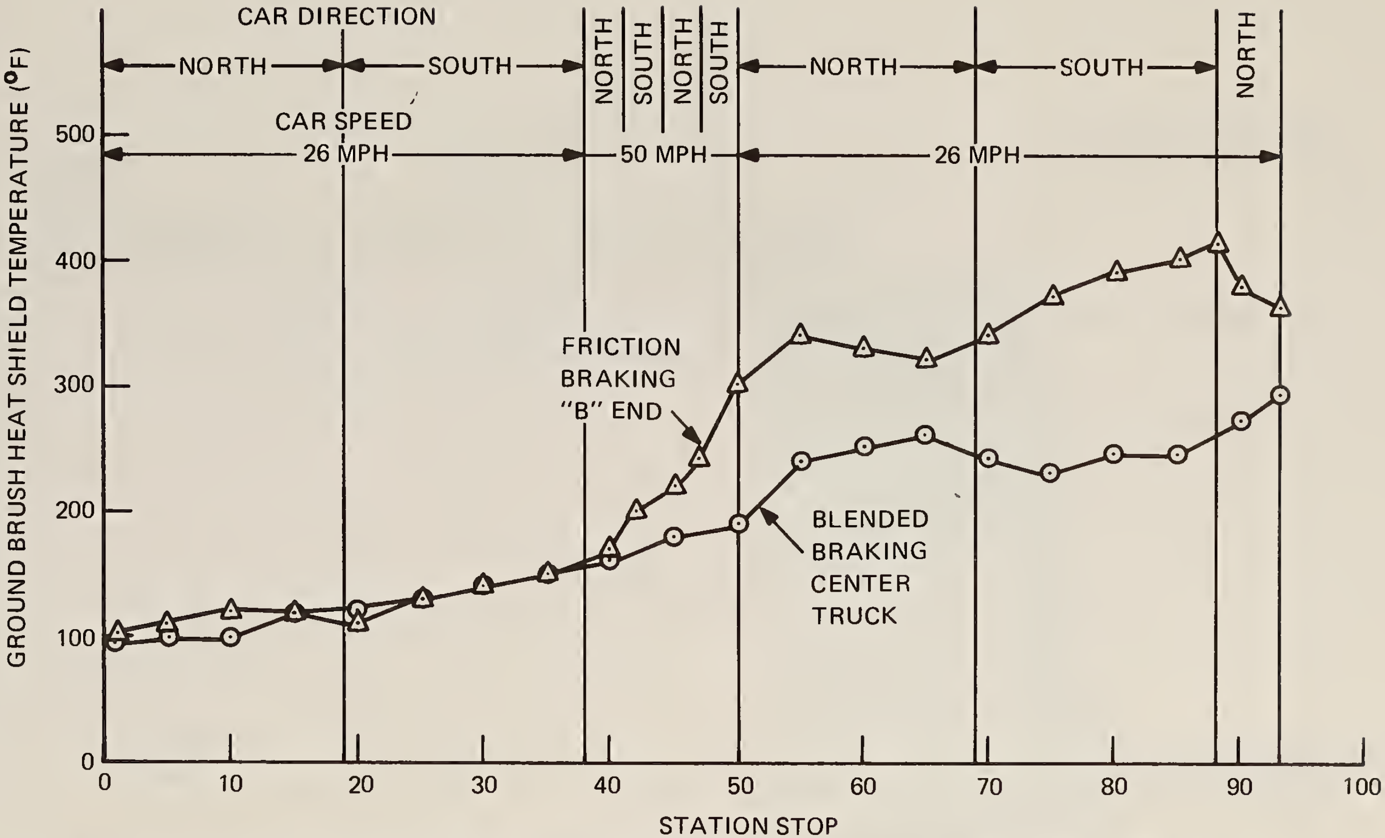


Figure 6–3. Simulated N-Line Duty Cycle at TTC Pueblo, Ground Brush Heat Shield Temperature

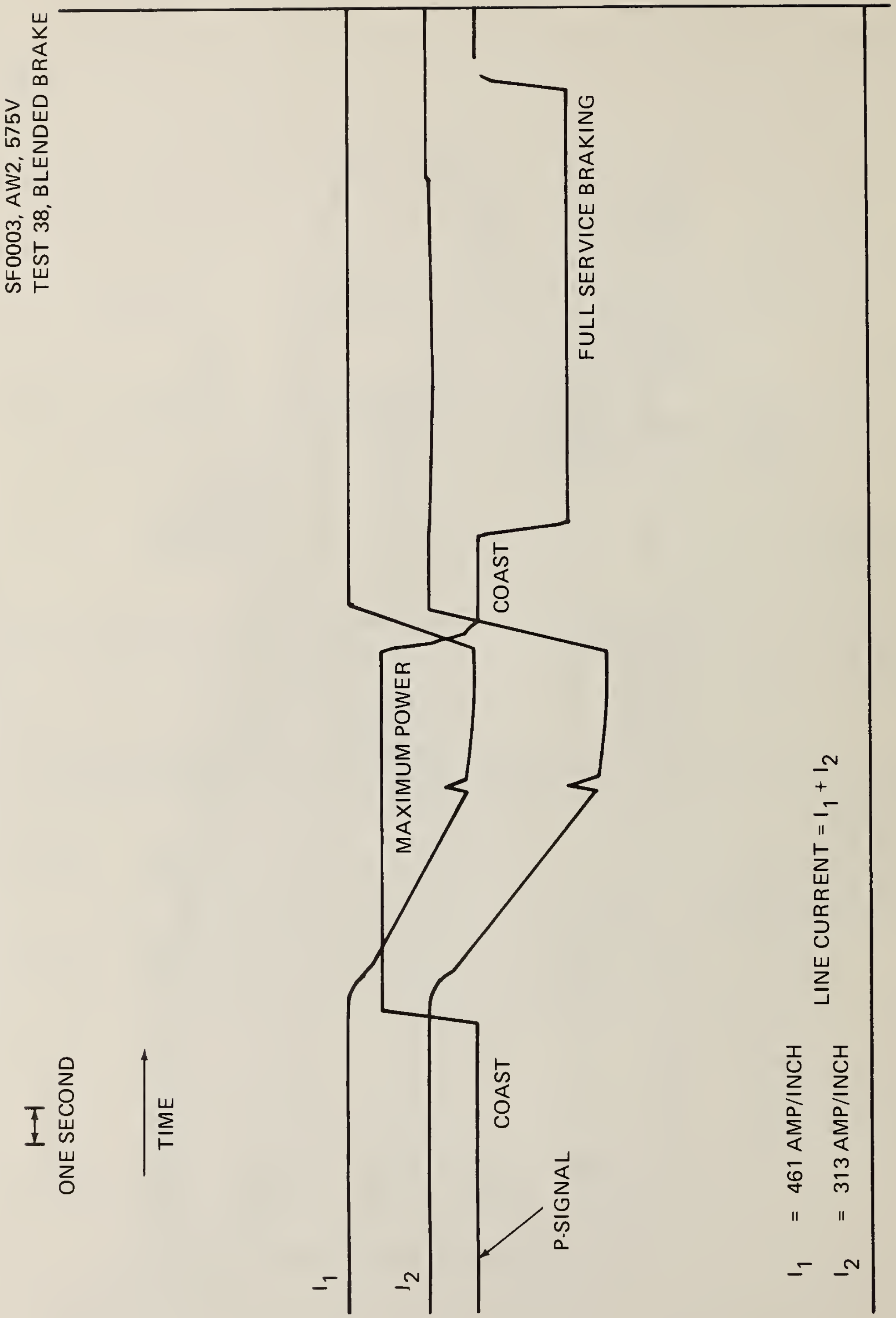


Figure 6–4. Typical SLRV Line Current Record

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